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# establishment techniques for forest plantations

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# FOREWORD

FAO is indebted to G.W. Chapman and T.G. Allan for the preparation of this document on establishment techniques for forest plantations. The first draft was prepared by Mr. Chapman, a forestry officer of many years' experience in the Mediterranean and Near East regions. It was based largely on the papers submitted to the FAO World Symposium on Man-Made Forests and their Industrial Importance, held in Canberra, Australia, in 1957, and supplemented by other available information. The draft was widely circulated, and many useful suggestions were received for its refinement. In the light of these comments, and with the aid of more recent literature, the document was revised and updated in 1977 by Mr. Allan, who also drew on his long experience of afforestation in Africa.

Appreciation is also expressed to H.C. Dawkins, L.R. Letourneau, A.I. Fraser and B. Kingston whose work is reproduced in the appendices.

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# PREFACE

The FAO World Symposium on Man-Made Forests and their Industrial Importance, convened in Canberra, Australia, in 1967, drew attention to the increasing contribution of man-made forests in the field of forest development and wood production. Estimates made at the time of the symposium were that a world total of about 80 million ha of man-made forests had been planted up to 1965, and that by 1985 the total might well reach 200 million ha (FAO, 1967). In some countries of the world, a substantial part of the national wood consumption is already met by wood production from plantations, and in other countries there is a growing recognition of the possibilities and advantages offered by man-made forests, even where considerable reserves of natural forest exist.

This document is intended to serve as a reference book on some of the principal methods of establishing forest plantations. Coverage is global, with some emphasis on techniques suitable for tropical and subtropical regions.

For the purposes of this book, the plantation establishment phase is considered to be that general period from initial site preparation to the stage when the plantation crop closes canopy. The book, therefore, covers site preparation, planting and direct sowing, early tending and protection operations, as well as the necessary operational planning measures required to ensure timely and efficient completion of activities. Subsequent managerial practices carried out after canopy closure and operations done prior to site preparation, such as nursery production and choice of species and sites, have been excluded.

The subject matter is treated on a broad base, covering the main techniques and general principles of plantation establishment and operational planning. Greater detail on specific practices for particular areas can be found by consulting handbooks or manuals prepared for individual regions or projects, many of which are listed in the extensive bibliography provided at the end of each chapter. An additional bibliography of general, comprehensive sources of information is given at the end of the book.

# CHAPTER 1

# SITE PREPARATION

## GENERAL CONSIDERATIONS

Site preparation as discussed in this chapter is confined to firm, well-drained or generally dry land sites, already occupied by a usually indigenous ground cover (more difficult sites are dealt with in Chapter 4). This vegetative cover can sometimes prevent the successful establishment of a new plantation crop by occupying and utilizing the required land, by creating excessive competition for available moisture and/or nutrients, by depriving seedlings of light or by hindering the introduction of techniques necessary for successful establishment. Under such conditions, a primary requirement is to determine efficient and economic methods of eliminating harmful competition. Sometimes removal of vegetation creates sufficiently favourable conditions for tree establishment without further assistance, but in other areas the main aim is to create conditions whereby regrowth and weeds can readily be controlled during the establishment period, which may cover a number of years. Site preparation is an early investment and often constitutes a major proportion of total establishment costs. The fact that such costs considerably affect financial feasibility underlines the need to use efficient and economic methods.

As the removal of an indigenous vegetative cover constitutes a major ecological change, no site clearing should take place without knowledge of what these effects are likely to be and without careful planning to ensure that cleared land is carefully and efficiently used and that necessary precautions are taken to prevent soil degradation or erosion.

In certain favourable circumstances, it may be possible to establish the plantation crop with minimum disturbance of the natural cover and minimal or no cultivation of the soil. For example, where fast-growing tropical pines are planted on short-stemmed grass sites, it is common practice to plant the seedlings without prior cultivation, the only preparatory work being to burn off the grass in the dry season preceding planting. At the other extreme, there are examples where dense tropical rain forest has to be removed, often under difficult conditions of climate and terrain, before planting can begin. Often the soils of such rain forests are fragile and great care has to be exercised if excessive erosion is not to ensue. Between these extremes, there is a great range of sites and conditions offering a number of options on how site preparation may be undertaken.

Site preparation using labour and handtools is the oldest and remains the most common method. More recently, particularly where the labour supply is restricted or costly, a number of mechanized techniques have been developed, many involving specialized equipment for clearing and cultivation. Site preparation in forest or woodland, particularly in hot climates, is extremely arduous and heavy power units can take some of the drudgery out of such work. Machinery offers high outputs per hour or per day, but involves a high capital expenditure and requires special operating and maintenance skills. A further innovation is the development of chemical weedicides which can be used in forestry to control or eliminate unwanted vegetation. Some chemical methods are used on an operational scale, but others remain at the experimental stage; for many there is incomplete information of their possible harmful effects on the general environment.

For any afforestation project, site preparation methods should be investigated, developed and assessed prior to initiating the project. In many countries, adequate manual techniques are established and known, but for some operations the employment of mechanized or chemical techniques may offer improved cost efficiency or opportunities to extend the scale of project. In the absence of any previous site preparation investigations, a series of trials is required to compare the standard local techniques with other methods which seem relevant to the sites being developed. The comparisons should be made on the same or highly similar sites and should not be confined only to site preparation but should relate the operations to subsequent establishment, tending and growth.

The general objectives of site preparation involving clearing of vegetation and/or cultivation are:

1) to clear the site of existing vegetation so as to reduce or eliminate competition which could prevent adequate establishment or adversely affect the plantation crop and

2) to cultivate the ground

   a) to facilitate planting and establishment and to encourage rapid root development,

   b) to reduce the weed cover,

   c) to reduce erosion by providing physical barriers to surface runoff and,

   d) where mechanized post-planting weeding is planned, at the time of cultivation or before to remove all surface or below ground obstructions likely to hinder weeding operations.

Under specified conditions only some of these objectives may apply to a particular area or project.

## MANUAL METHODS

Manual methods for clearing ground cover and for soil preparation are in use predominantly under the following circumstances:

1) where the ground cover requires a minimum of disturbance prior to planting or seeding,

2) where labour is plentiful, cheap and efficient or, in some cases, where it may be socially desirable to employ labour in preference to other alternatives, and

3) where machinery is not available or where the terrain is too steep, too rocky, too wet or otherwise unsuitable for its operation.

## Grass or Shrub Covered Sites

### Direct Planting without Clearing

On some sites where the ground cover consists predominantly of grass species or of low, shrubby species, direct planting may be carried out with a minimum of previous site preparation. Such is the case in the pine plantations of Zululand in South Africa where pines originating primarily from southern U.S.A. (Pinus elliottii) have shown a remarkable capacity for growing up through the undisturbed mature grass, provided that their tops are kept free by slashing. No form of soil preparation is needed and the plants are simply inserted into holes or slits made with a trowel.

Direct planting without previous site preparation is also practised in many northern temperate countries, for instance on old clear-felled conifer forest land or dry heath moors, where soil nutrients and moisture are sufficient both for the newly planted seedlings and for the native vegetation. Sometimes the retention of ground cover is even desirable because of its beneficial effect in protecting the young forest plants from frost or from exposure or in reducing the risk of erosion on steep or hilly sites. The essential feature in the direct planting method is that the forester relies mainly on post-planting weeding and slashing to keep the forest plants from being suppressed by the native vegetation.

### Strip and Patch Clearing

In cases where the competition of herbaceous or shrubby vegetation is harmful to the new forest crop, as happens frequently in the Mediterranean region and other areas subject to pronounced dry seasons, it is necessary to clear the vegetation prior to planting. Where burning cannot be safely managed and where it is too costly to clean cultivate the whole area, clearance of the vegetation is limited to relatively small patches or narrow strips, in which the tree seedlings are later planted. The cleared patches or strips should not be less than one metre in width, preferably 1.5 metres, and should be well cultivated to good tilth before sowing or planting. The tools most commonly used for this work are the mattock, heavy hoe and grubber. Most effective is the mattock, which has a hoe or digging blade on one side and a pick or cutting blade on the other.

On hillsides liable to erosion, the cleared patches and strips are usually sited on the contour, the uprooted vegetation being stacked along the lower edge as a precaution against soil wash. Where soil conditions permit, contour strips can be ploughed.

In Morocco, the soil preparation method most used in shrub-covered foothills for planting Eucalyptus gomphocephala and Pinus halepensis is to clear and cultivate by mattock patches of land (potets) 50 - 70 $cm^2$. Frequently these cultivations are combined with soil and water conservation measures such as contour ditching or construction of narrow terraces (gradoni or banquettes).

### Burning Off

Controlled burning of grass or low bush covered sites prior to planting is common practice in many countries and can be said to be the oldest method of ground clearance and may be the cheapest. Controlled burning requires careful planning. The general approach involves cultivating or clearing a fireline or break around the area and initially burning a strip at least 50 m wide into the wind, with the fire being kept under control by beaters. Once a sufficiently large downwind strip is clear of inflammable matter, the rest of the perimeter is set alight and the fire is allowed to run with the breeze. This main burning is best done in the evening or at night when winds generally drop and the fire is less likely to get out of control.

Burning in some cases may be harmful, for instance by stimulating the regeneration of undesirable species, by aggravating soil erosion or by promoting the outbreak of fungus diseases (e.g. Rhizina undulata on Pinus sylvestris).

## Bush or Forest Covered Sites

On sites covered with woody vegetation there are two major clearing techniques : 1) felling, where roots are left in the ground or 2) stumping, where the roots are extracted.

### Felling without Root Extraction

#### Clear Felling

The clearing of more or less densely covered bush or forest land is almost invariably costly in manpower, though the financial cost to a project may be reduced if a good proportion of the wood being cleared carries some commercial value as firewood or charcoal, posts, poles, pulpwood or even timber. In such cases, the land clearing operation is often contracted. The terms of such contracts naturally vary widely throughout the world, with much depending on the value and usefulness of the material to be cleared. In favourable circumstances, clearing may yield a net income, recouped either in cash or commuted for additional site preparation work such as fencing, draining, or construction of access roads.

In other areas, the site to be prepared for planting may be previously logged forest in which all or most of the usable material has already been removed, leaving only the felling debris mingled with unmerchantable stems, weeds, coppice sprouts, an understory forest or bamboos. There is then little alternative but to move in with gangs of men to cut and clear the vegetation for broadcast burning or to pile it in heaps or rows where it can be burned or left to rot.

In Papua New Guinea, native rain forest is clear-felled from plantation sites by manual methods. Labourers first go through the area cutting all ground vegetation and stems up to 7.5 cm diameter. This clears the way for the next gang of men who fell all the stems above this diameter and at the same time trim off the branches from the larger felled trees. Some six to eight weeks later, during a few days dry spell, the cut-over areas are systematically burned, and generally all but the heavier logs are consumed. The brushing and felling work alone requires up to 50 man-days per hectare.

In Ghana, tropical high forest is also manually cleared for planting. Following selective logging, understocked sites are cleared of underbrush and small trees by gangs of labourers using machetes. Larger trees are felled with power saws or poisoned. Some de-limbing is done in association with felling to facilitate a good burn, but stacking and windrowing are not practised. Broadcast burning is done in the dry season. The felling and burning operation require an average of 86 man-days/ha.

Similar large-scale manual clearing of commercially poor lowland tropical rain forest is done at the Jari River project in the Brasilian Amazon region, where large gangs of closely supervised contract labour have replaced heavy tractors (Palmer, 1977).

In Papua New Guinea, Ghana and Brasil, the species subsequently planted are light-demanders. These require total felling of existing vegetation, but with more shade-tolerant species it may not be necessary or even desirable to remove all the indigenous forest growth from the site. Consequently, systems of partial clearing have evolved which may be called "strip or line clearing" where the vegetation is totally cleared along lines or bands at fixed intervals, and "release clearing for underplanting" in which the ground vegetation and understory species are totally cleared while the overstory of larger stems is thinned out systematically so that the crowns of the remaining stems cast a mosaic pattern of light and shade on the ground.

Strip Clearing

Strip clearing has been widely used in the tropics in connection with : 1) enrichment planting, aimed at improving the percentage of desirable timber species in natural forest without eliminating existing useful trees and 2) conversion planting, aimed at the complete replacement of the existing vegetation by an entirely new man-made forest (FAO, 1970 ). Although these two reforestation methods differ in aim, the techniques used are often very similar. For both, fast-growing, light-demanding trees are planted in lines cleared through the existing forest after varying reductions in the canopy; for enrichment planting some of the trees of the natural forest are intended to be preserved, while for conversion planting all are eventually removed. The width of the cleared strips and their frequency varies, but the method of carrying out the work is essentially the same.

The first step is to establish a cleared base line (if no roads or suitable paths are available) at right angles to the direction of the future planting lines. This direction may be determined by considerations of topography, of future extraction routes or of lateral shading (in many West African countries an east-west orientation is preferred). The planting lines are then "blazed out" at right angles to the base line by a brushing gang, the correct direction being maintained by a prismatic compass or a simple sighting instrument. The blazed lines are then cleared to the required width by cutting and felling gangs. The resulting debris is piled to rot along one edge of the strip or, preferably, burned if atmospheric conditions permit. The cleared strips are hoed in lines or in spots ready for planting or sowing. Trees in the bands of forest between the cleared strips which may cast overhead or lateral shade on the planted trees are either felled, ring-barked (i.e. girdled) or poisoned, the intensity of removal depending on whether the objective is enrichment or conversion.

Although line planting has been widely practised in the tropics, it has met with varying degrees of success; there have been a number of attempts to identify the reasons for success and failure (Catinot, 1969; Dawkins ex Lamb, 1967; Groulez, 1976; Jackson, 1974 and Lamb, 1969). Most successful have been the line conversion plantings in francophone West Africa. Line enrichment planting, on the other hand, has been abandoned in some countries, after having been practised for a number of years. In some cases this is because the techniques used were unsuccessful; but many of these failures could have been avoided had the general criteria for success as formulated by Dawkins (ex Lamb, 1967), and reproduced in Appendix A, been followed. In particular, early and complete opening of the overhead canopy and the use of species capable of rapid initial growth and tolerant of weed competition are necessary (Jackson, 1974). In other cases the increased demand for forest products, especially from thinnings, has made close plantations more attractive than line plantings. On the whole the tendency is to change from line plantings to more intensive forms of forest management, such as close plantations or taungya plantations. Line planting, however, is still used extensively in some countries and remains under study in a number of others. It can still be of great value in regenerating exploited forests when more intensive management is uneconomic or where natural forest conditions must be maintained to protect the environment.

In the British Solomon Islands Protectorate, for example, line planting has become the standard technique for large-scale reforestation of cut-over native forests (Jackson, 1974). Lines are cut 3 m wide at 13 m intervals and the plants are spaced 3.6 m along the line. All stems in the remaining overwood larger than about 5 cm diameter which cannot be felled economically with a machete are frill-poisoned with sodium arsenite two months after planting. The first two line cleanings are done to ground level at 2 - 3 month intervals. Subsequent cleanings are done to knee height at 3 - 4 month intervals during the first 18 months. Thereafter climber cutting is practised as required. In 1970 labour requirements, excluding supervision, were 55 man-days/ha, broken down as follows:

| Operation | Man-days/ha |
|---|---|
| Site preparation (line clearing, poisoning, regeneration roads) | 19 |
| Planting and plant production | 11 |
| Tending (cleaning, climber cutting, boundary maintenance) for three years | 25 |

Release Clearing for Underplanting

This method may well be considered as an extension of, or deriving from, the European system of shelterwood regeneration. It has application particularly where:

1) the species to be introduced needs (or tolerates) overhead shelter in the earlier years after planting,

2) the existing forest contains a relatively high number of large, undesirable stems whose removal would be unduly costly or difficult, or

3) the existing forest contains a number of valuable timber species which it is desirable to retain, the aim of new planting being either to enrich the forest with the same species or to introduce a replacement crop of some other species.

The usual procedure is to brush or cut away all the low vegetation (small coppice and trees under 10 cm diameter) which is then piled and, where possible, burned, leaving the ground surface more or less freely accessible for tree planting. Some of the remaining trees are then ring-barked, leaving sufficient stems in the overwood to produce the desired mosaic of light and shade of the forest floor. The remaining overwood is killed off selectively by ring-barking in subsequent years, depending on the progress of the underplanted crop. The ideal density of the overwood is one which maintains sufficient shade to keep the forest floor reasonably free from weeds and coppice regrowth while letting in sufficient light for satisfactory establishment of the new forest crop.

Ring-barking is most effective if carried out in the season of active growth. Care should be taken to remove a complete band of bark, cutting through into the wood of the stem to ensure that the cambium is completely severed. There are many species which are not killed completely in the first year after ring-barking and linger for several years before finally dying. It is becoming an increasingly common practice to ring trees by chemical methods, as described later in this chapter.

Unless the overwood stems have some commercial value, in which case they would be felled and extracted through the young underplanted forest, normal practice is to leave the dead overwood stems to "rot on their feet": the side branches fall off gradually when rotten and finally the hulk of the old trunk falls; damage to the new plantation is usually negligible. However, on steep slopes experience has shown that the trunk, when it eventually falls, can roll and cause considerable damage to the young crop. There is also the problem of the danger of falling branches from the dead trees which makes labour reluctant to work in treated areas.

One example of underplanting after release clearing, can be found in the United Kingdom where *Tsuga heterophylla* is often planted under existing hardwood cover such as birch (*Betula*), old oak (*Quercus*), coppice or ash (*Fraxinus*).

## Stumping

Stumping is necessary where it is envisaged that there will be subsequent cultivation, often mechanized, requiring the elimination of roots. Manual stumping is the oldest and most common means. The work may be done by direct or contract labour using, for the most part, spades, hoes, mattocks and axes. The operation involves excavation, cutting of roots and felling and in most instances includes removal of the whole standing tree at the time of stumping. The soil from around the tree is dug out; the depth and the width of the excavation varies with the size of tree and root system. On completion of excavation, the lateral roots are severed and the tree is then felled by cutting the taproot. In Nigeria, output varied with unit basal area: savanna with a basal area of 9 $m^2$/ha required an average of 65 man-days to stump one ha whereas heavier woodland at 13 $m^2$/ha required 123 man-days (Allan and Akwada, 1977).

Manual stumping is an arduous and highly labour intensive task, still widely practised in African savannas. (Courtesy T.G. Allan)

## Disposal of Debris

When the felled vegetation is sufficiently dense to support a hot burn, it can be burned in place without piling on windrowing. In other areas, labourers cut and clear the felled material and pile it into heaps or rows clear of the planting lines where it can be burned or left to rot. If the piled rows are not burned, gaps should be left at intervals to allow ready access for tending or for fire fighting. For burning, the debris is often piled into windrows or cut into billets which are heaped into tight piles and stacked around the larger timber to facilitate ignition and burning. The burning of windrows is described further on page 21, and the subsequent operation of plantation layout is treated on pages 59 and 142.

When clearing occurs close to centres of population, it may be possible to dispose of this debris as firewood, which is not only sound utilisation of the resource but can be socially and economically beneficial to the plantation project. Opening areas to charcoal production is another possibility. Charcoal production allows a more complete utilisation of the debris than firewood, and being lighter can extend the economic transport distance.

## Taungya

Agrisilviculture may be defined as a system combining agricultural crops and/or livestock with growing trees, with the aim of optimising the total production per unit area compatible with the primary objective and sound land use. Within this concept may be included the taungya, or shamba, plantation system where a forest crop is raised in combination with a temporary agricultural crop. Under this system, manual site preparation is carried out by cultivators who use the land for food production during the period when the plantations are being established.

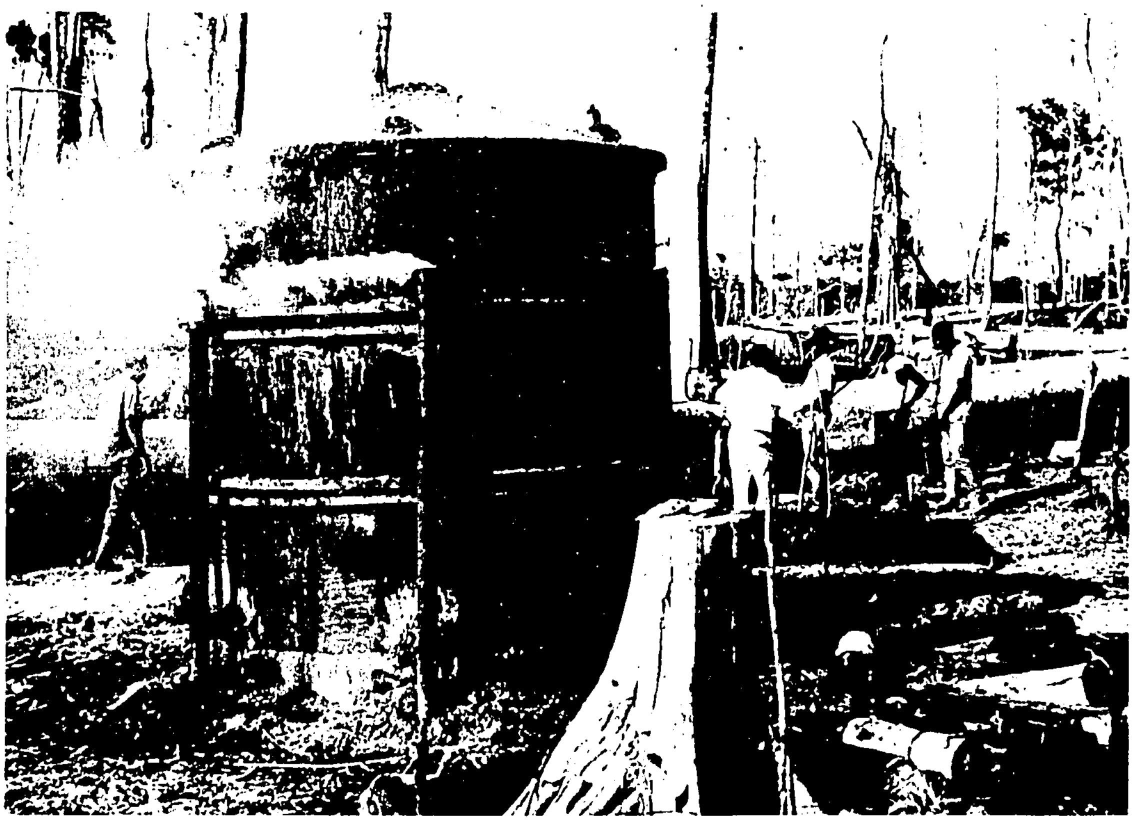
Taungya is a Burmese word for a cultivation plot of the type of shifting cultivation practised in the hilly evergreen forest areas. Shamba is the Kiswahili word for a similar clearing in savanna or forest in East Africa.

The taungya plantation system is very often developed in tropical areas where shifting cultivation is common. Shifting cultivation is a primitive but effective form of agriculture where land is unlimited. The essential features are land in which the level of fertility is quickly diminished under cultivation, and where even if artificial fertiliser could be effective the cultivators are too poor to afford them. Instead of fertilisers, a tree fallow is used to replenish fertility. However, wherever land is limited in relation to an often expanding population, the cultivation cycle is shortened, with consequent losses in fertility, and soil degradation often ensues.

The development of the traditional taungya plantation system is only possible where there is land hunger and industrious, landless cultivators. Under this system, the cultivator is allotted an area of natural forest which he clears by stumping, cutting and burning. The plot is clean cultivated with hand tools and used for the production of food for the cultivator and his family; any surplus crops are sold for income. The plantation tree seedlings are introduced into the agricultural crop at a stage when they will be weeded for at least a year and should readily become established when the cultivator abandons that area for food production and moves on to clear another taungya area.

In parts of southeast Asia, traditional taungya is used extensively to create teak plantations. In Thailand the system is associated with the establishment of forest villages; whereas in the Solo water catchment area in Indonesia the growing of trees is combined with a grass fodder. In Sierra Leone the cultivation of taungya agricultural crops is limited to one year, and the trees are incorporated as soon as clearing is completed. In the Kenya shamba system, the cultivators were employed by the forest department for nine months or more per year.

In Ghana much of the heavy debris remaining on planting sites following selective harvesting, manual clearing and broadcast burning of the tropical high forest is utilized for charcoal production. Subsequent planting and tending is done manually. (Courtesy D.A. Harcharik)



A variation of the traditional taungya system used extensively in Nigeria (where it is called "farming for pay" or "direct taungya") and in Ghana (called "departmental taungya) has the following main features (Olaweye, 1975):

1) The farmers employed are recruited as wage-paid employees of the forest department.

2) Land hunger is not a prerequisite to taungya.

3) The forest department owns both the farm crop and the trees.

4) There is no allocation of individual farm plots.

Although there are many variations of the taungya system, incentives have much to do with participation; the general inputs and benefits can be those as shown in the following table.

| | Inputs | Benefits |
|---|---|---|
| Cultivators | Labour (in return for the use of land and for wages) | Income from employment or incentives<br>Food for family<br>Cash from sale of surplus crops<br>Housing, services, education facilities and infrastructure |
| Forest agency, or government | Land<br>Management, tools and equipment<br>Housing and services<br>Employment | Reduced direct plantation establishment costs<br>Long-term wood production<br>Reduction in shifting cultivation |

Not all of these factors apply to every case but they constitute a general outline. For the landless shifting cultivators the provision of land for food production is one of the main incentives influencing participation in taungya plantations.

The origins of the taungya system lay in the desire to displace harmful shifting cultivation and to reduce forest plantation establishment costs. As a form of controlled shifting cultivation, which minimises damage to the soil by providing an effective tree cover, the system does not cause the stress that too great a change in agricultural practice could create for traditional cultivators. In the past, taungya has reduced the cost of plantation establishment. More recently, some if not all, of these apparent savings have been applied to forestry community development, as in Thailand and Kenya, ensuring that the community is to some degree recompensed for its contributions to the system. Traditional taungya may be considered an intermediate form of land use in the development from shifting cultivation to either sedentary agriculture or full (forest) employment, or possibly to a mixture of smallholding and part-time employment.

The intensive cropping of taungya plots reduces fertility of the soil, particularly as additional fertiliser is seldom applied and the food crops are in competition with the plantation trees. In Kenya, for example, trees grown in clean cultivation showed a 15% better height growth than those in a maize shamba and an 8% increase over those in a bean shamba (Kenya Forest Department, 1967). In another region, Turbo, no comparative fall in growth was recorded in fertilised maize.

## MECHANIZATION AND MECHANIZED METHODS

Labour can do almost all of the work in establishing a forest plantation, and even on a large scale can be efficient and economic. In Brasil, for example, clearing of the native forest was initially done by tractors, but high costs and low production led to the use of manual methods and now nearly all the field operations are carried out by large gangs of contract labour working under supervision of project authorities (Palmer, 1977). In other areas, however, the sheer size and cost of the labour force required for large-scale projects may preclude this as a realistic possibility. Mechanisation, then, is an important alternative.

Many of the site preparation operations described in the preceding sections can be mechanised, and there is a range of machines and equipment available for such operations. The main object of mechanisation in plantations is to carry out selected operations effectively and economically by employing machines. Where operations are done satisfactorily and economically by manual labour, and where there is a plentiful supply of suitable labour, then only those operations beyond the capability of the labour and supervisory services need be mechanised.

It is frequently suggested that mechanisation reduces employment opportunities. In comparing the relative merits of labour employment and mechanisation, it is necessary to balance social benefits against the cost benefits of using more efficient alternatives. A soundly based, successful project, for example, whether mechanised or labour-intensive, will in the long term provide more permanent direct employment, and additional indirect employment in wood processing industries, than a non-viable undertaking. In general, therefore, where mechanisation of larger scale plantation projects reduces costs and is a factor in project viability, it seldom results in jobs being lost but rather increases employment possibilities within the economic criteria established by management and planning.

Mechanisation in the strict sense refers to the introduction of machines to supplement manpower used in carrying out selected operations. In this publication the term is used primarily to cover mobile engine powered units such as tractors, but it also includes the use of chain saws and other hand-held power units, the operation of which is labour intensive. Use of draught animal power is treated separately.

### Mechanisation Principles

When mechanisation is planned, there are certain basic principles which require consideration and which apply not only to the land preparation phase but also to the entire plantation rotation.

In selecting machines and implements for plantations, it is essential that equipment should be fully suited to the operations required of it. It might, for example, seem beneficial to purchase a machine or equipment which is capable of carrying out a number of operations, but if such a compromise results in the selection of equipment not completely suited to the critical task then its real usefulness may be at slight or at most somewhat devalued. The concept underlines the need for trials to determine types of equipment best suited to and most efficient for specified operations.

The planning of field operations should aim to maximise the effective use of selected machines. In plantation layout and design, large blocks offer greater possibilities of efficiency than small and diffused areas. The road and ride pattern should allow ready access and turning space for mechanical equipment. To reduce the proportion of unproductive turning time for tractors, the planned layout should allow long tractor runs, preferably in two directions. Spacing is another critical factor affecting the tree crops and equipment efficiency and offering a range of management options requiring evaluation and judgement. For example, a spacing of less than 2.8 m is seldom possible when normal agricultural tractors are used.

A major requirement is that every machine operator should be fully competent in the operation of the machine or equipment in use. Poor driving and misuse of equipment commonly reduce tractor productivity by more than fifty percent. In many developing countries where there is a shortage of skilled operators, training facilities are necessary if the required levels of operating skill are to be attained. For trained operators to maintain and improve their work, it is necessary to provide financial or other incentives based on the serviceability and productivity of the equipment used.

Critically important in mechanisation is the provision of an adequate repair and service organisation staffed by skilled personnel with an assured supply of spares and replacements to ensure early and effective maintenance. As is the case for operators, in many parts of the world there is a need to provide training in repair and maintenance. A machine is only of real value when it can perform its prescribed work efficiently.

Mechanisation is a costly process, and its introduction requires a clear understanding that the objectives of the project are to be achieved efficiently and economically. For effective management, it is necessary to cost the various mechanised methods or alternative methods of carrying out particular plantation operations. To maintain the incentives for success, mechanised operations should be organised on as sound a commercial base as possible.

In the early stages of plantation development, mechanisation can and does occur without full implementation of the main requirements discussed above but, of course, not without creating problems and some loss in effectiveness. To commence large-scale operations, however, without due consideration of the principles outlined can only lead to the creation of an inefficient and uneconomic mechanised enterprise.

## Advantages and Disadvantages of Mechanised Land Preparation

The main reasons for selectively mechanising land clearing operations generally concern the availability of labour, cost efficiency, scale of operation, timeliness of operation and the quality of work performed.

### Labour Availability

The absence or shortage of adequate labour can be a primary factor requiring the introduction of mechanisation. The optimum time for carrying out much of the land preparation work is when soils are moist,and in many regions this coincides with the period of maximum agricultural activity, with consequent local and seasonal labour shortages. Again many of the land preparation activities entail heavy and arduous work and the application of selective mechanisation eliminates the manual drudgery from such tasks.

### Cost Efficiency

In general, large-scale land clearing can be done with greater cost efficiency by mechanised techniques than is possible by manual methods. A further factor, particularly in developing countries, is the tendency for labour rates to increase at a faster rate than machine costs, a trend which increases the comparative cost efficiency of mechanised methods. Where there is large-scale unemployment, however, the application of shadow costs for labour can indicate social cost benefits favouring labour intensive methods.

Scale

Scale of operation is related to efficiency. There are no hard and fast rules as to the level or scale at which mechanisation should or may be introduced. For selected projects all the relevant factors have to be studied and evaluated before any decision on the possible timing and degree of mechanisation is possible. In general, for larger scale projects problems of control and productivity of labour tend to justify the introduction of selective mechanisation. The economies from increased usage of machines at the larger scale further favour mechanised development.

Timeliness

In plantation development timeliness of operation is often critical; for example, late land preparation can cause delays in subsequent operations, often with adverse effects on both the plantation crop and on cost efficiency. Where labour or related elements limit rates of production, mechanisation with its generally fast work rates provides a method of accelerating productivity and completing operations in timely fashion.

Quality

As a consequence of the considerable power and weight of machines, the quality of mechanised land clearing tends to be superior to that of hand labour. Mechanised stumping or knockdown generally removes a greater proportion of roots to a greater depth than comparable manual operations. Similarly, plough or harrow cultivation is more effective than cultivation by hoe.

Common constraints to mechanisation in plantation development include:

1) difficult terrain where steepness, gullies or rocky outcrops preclude the efficient use of machines;

2) the high initial cost, often in foreign currency, of setting up a mechanised operation, together with the high and rising operating cost of fuels and oils;

3) poor tractor serviceability due to lack of skilled personnel to manage, operate and maintain equipment, often aggravated by

    a) lack of spare parts,

    b) bureaucratic delays in ordering or paying for parts or services,

    c) poor land clearance resulting in damage to cultivation equipment in subsequent operations and/or

    d) lack of personnel incentives;

4) poor machine operation often resulting in unnecessary soil disturbance or compaction detrimental to subsequent plant growth and

5) the opinion, often irrational, that mechanisation causes redundancy or loss of job opportunity.

## Land Preparation Operations

This section is primarily concerned with mechanised methods for the removal or destruction of vegetative cover and the cultivation of soils prior to planting or seeding. In many parts of the world, particularly in areas with a marked dry season such as in savannas, successful plantation establishment involves clean weeding in the initial stages. Except on small areas or where taungya is possible, clean weeding necessitates a considerable input of mechanized cultivation. To allow efficient mechanised weeding, land should be free of all surface woody vegetation and of all roots and stumps to the maximum depth of penetration of the weeding implements, which requires the stumping of all standing trees and the disposal of all stumps, roots and other woody debris from the site.

The main operations are:

1) felling or stumping of natural woody vegetation by knockdown,

2) windrowing,

3) cleaning up,

4) burning or disposal of debris,

5) laying out and

6) pre-planting cultivation.

Operations 1 to 4 presuppose a natural woody vegetative cover which has to be removed or destroyed before plantation development can proceed. On grassland sites development would be initiated at operations 4, 5 or 6, with burning, when used, confined to eliminating the grass cover in the dry season prior to planting. Cleaning up, burning and laying out are generally manual operations, although some supplementary mechanised inputs may be required.

### Removal of Natural Woody Cover

There is a considerable range of mechanised land clearing techniques; the main methods are adapted to the type and density of vegetation, topography, climate and subsequent establishment techniques. In areas where no mechanised weeding is planned, for example, the removal of roots is optional, and trees can be felled at or above ground level. Where harrow weeding is intended, however, in addition to all woody vegetation, roots and stumps should be cleared to the maximum depth of cultivation. Vegetation density is important in that the heavier the tree cover the greater the power necessary to remove it. It follows, therefore, that equipment and techniques will vary over a range of vegetation types such as thicket, woodland or rainforest. Slope and terrain place some limit both on what may safely be cleared and how the selected technique will be applied. Rainfall also affects many facets of clearing, but is most critical to the timing of operations. It is recommended that clearing take place only when soils are moist because roots are extracted freely under such conditions and because at this time tree stems are full of sap and are less liable to breakage.

### Felling without Root Extraction

Mechanised cutting employs crawler tractors with front-end mounted sharp blades to cut and fell trees at or near ground level. An angled and sharpened K.G. blade is suitable for shearing thicket or woodland trees up to 30 cm diameter or larger; the V-shaped blade is suitable for larger forest trees.

On smaller areas or on gradients where tractors cannot be used, trees may be felled using a range of chain saws; for brush or thickets a portable scrub cutter is useful. This is a small circular saw at the end of a metal rod, powered by a small back-carried petrol motor.

In the U.S.A. brush or thicket growth is extensively felled using heavy rolling choppers, which comprise a large drum with cutting blades towed by a crawler tractor. They cut the woody vegetation into small pieces and incorporate the debris into the soil. There is a range of makes and types of choppers from small to very large single drum types to multiple-drums pulled in tandem. The cutting and crushing effect can be increased by filling the drum with water. In general, unless a speed of about 8 km/hr or more is maintained, the drums roll over the vegetation and give inadequate chopping. To maintain speed, a direct-drive power unit is required.

The light-weight 4½ ton model chopper filled with water requires a 35 to 60 drawbar horsepower and is effective on woody stems up to 5 cm diameter. The 8 ton model requires a 50 to 75 hp drawbar pull and is effective on brush to 8 cm diameter. The 11 ton model requires 70 to 125 hp drawbar and is effective in chopping hardwood brush up to 10 cm diameter. Even larger models to 16 ton requiring a 250 hp drawbar pull are available for dense brush and extensive areas. The size of chopper needed for a particular job is determined largely by the density and size of the hardwood scrub species. In trials on sandy soils in southeastern U.S.A. (Burns and Hebb, 1972) it was found that the 11 ton model was more effective than either of the lighter types and that it killed more hardwoods of all sizes and resulted in higher survival of the planted pines. These trials were limited and did not include choppers of greater weight than 16 tons.

Fleco Corporation (1968) gives the following estimates of chopping productivity:

| Clearing Unit | Output in ha per hour |
|---|---|
| 385 FWHP 1/ + 16 ft (4.9 m) chopper | 1.5 to 4.1 |
| 216 DBHP 2/ + 14 ft (4.3 m) chopper | 1.3 to 2.3 |
| 52 DBHP + 7 ft (2.1 m) chopper | 0.7 to 1.4 |

A single chopping treatment does not provide sufficient control of hardwoods, regardless of the size or weight of equipment used. Sprouts develop at the root collar and this requires a second operation. This applies to all tree cutting operations, and unless there is a subsequent effort to kill the stumps, coppice or sucker regrowth will occur and the woody cover will quickly re-establish itself.

In Turkey, an Australian made "tritter" or "land conditioner" was used to macerate maquis scrub (*Quercus coccifera*, *Arbutus unedo* and *Erica* spp.) of up to 8 cm diameter (Deveria, 1977). The tritter is a towed scrub clearing machine of varying widths; that tested in Turkey was 1.58 m wide. It is driven from the power take-off of the towing tractor by V-belts and requires a 100 hp rated gear box and a speed reduction box. The machine breaks up the woody vegetation by the action of a flailing hammer, leaving a mulch of chopped vegetation on the soil. Performance depends on vegetation size and density and the forward speed of the tractor, the size of material it can deal with is inversely proportional to the speed. For typical maquis in Turkey an average clearing rate of 0.28 ha/hr was achieved.

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1/ FWHP = Flywheel horsepower

2/ DBHP = Drawbar horsepower

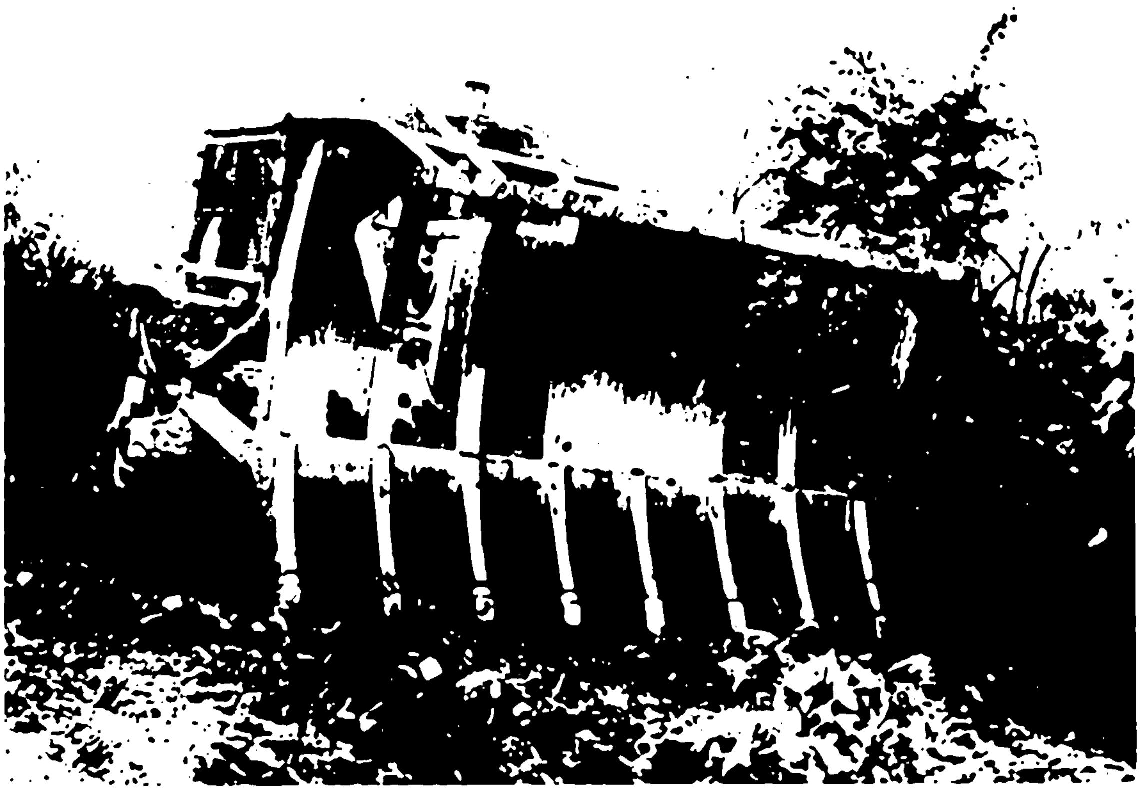
A County 4 x 4 wheel-tractor with rear-mounted tritter is used in Turkey to pulverise maquis in preparation for ploughing. A bankeman keeps watch for boulders. (Courtesy E.N.G. Cooling)

Removal where Roots are Extracted

In mechanized stumping or knockdown, crawler tractors and matching equipment are used to push or pull over standing trees while extracting the roots in the same operation. A main objective in these mechanized operations is to minimize soil disturbance; therefore none of the techniques incorporate digging or scraping.

1. Single tractor techniques

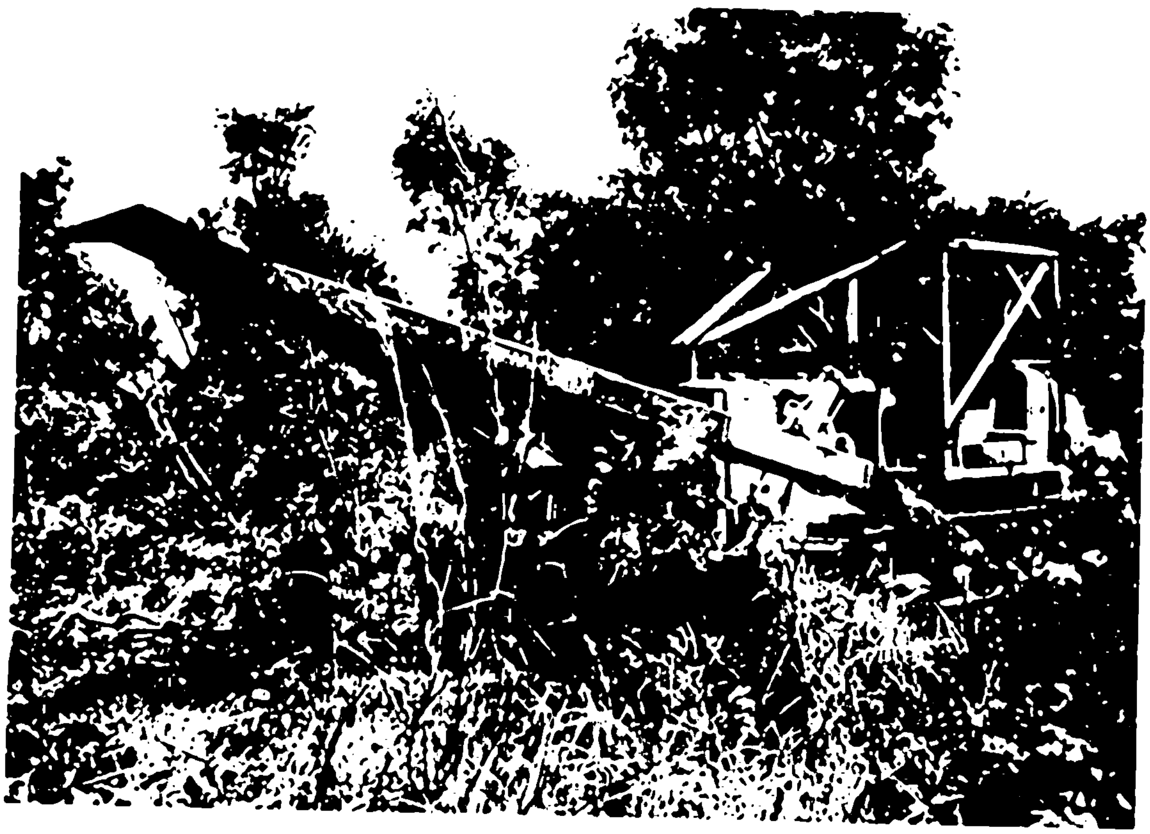
One of the better units for knockdown is a crawler tractor with a front-mounted application rake with top pusher bar. In woodland, for example, the tractor makes a pass at a standing tree by applying the pusher bar as high on the bole as it will reach and pushes the tree over. The rake is then lowered and applied to the exposed root system; the roots and main laterals are ripped out of the ground and the tree may be pushed for windrowing. The tractor then reverses before advancing to the next tree where the operation is repeated. Where a larger tree will not readily yield to the pusher, rear mounted rippers are lowered into the soil and the tree is circled to cut lateral roots. Such a tree is then usually fairly easily pushed over.



The front-mounted rake is suitable for light clearing and windrowing. In Turkey it is attached to the C-frame of a tractor and is used for clearing and piling degraded oak coppice and similar vegetation of small diameter and large root mass. (Courtesy E.N.G. Cooling)

The system may be adapted for heavy or rain forest vegetation by carrying out the work in two phases. First, a tractor fitted with an angled blade (a K.G. blade without the knife edge is satisfactory) and hydraulic tilt rams advances through the forest pushing over all undergrowth and small trees. Following this, when visibility has been improved, a tractor fitted with a tree stinger advances through the area and pushes over all the remaining large trees. In practice, the work is usually carried out by two tractors working around the forest in circular fashion. The tractors operate individually, with the understory clearing tractor usually at least 100 m in advance of the tree pushing tractor.

A crawler tractor fitted with a hydraulically operated bulldozer was previously the most commonly used machine for clearing scrub. Although still used, especially in small areas, the bulldozer is considerably less efficient for clearing than a pusher and rake. In most thicket or brush a heavy duty clearing or grubbing rake is a better attachment for readily extracting roots and stems.



A crawler tractor fitted with a tree stinger can be used to push over trees in woodland or rain forest which are too large for efficient clearing with chaining units or more conventional bulldozer or angledozer blades. (Courtesy T.C. Allan)

2. Chaining techniques

Chaining employs two crawler tractors with front-mounted blades or rakes and between them a rear-hitched heavy 90 m or longer anchor chain. In areas with larger or strong rooting trees, it is necessary to have additional or follow-up tractors fitted with a tree stinger to push over any tree holding up chaining progress.

In woodland the two crawler tractors advance at the same steady speed some 15 to 25 m apart dragging the chain behind. The distance apart varies with the density of the trees; the greater the density the closer the tractors have to operate. The outer tractor travels along the outside of the uncleared bush, and the inner tractor, 15 to 25 m inside the bush, advances parallel to the outer tractor and in as straight a line as possible. It is important that the tractor operators are able to see one another and that the outer driver maintains the same speed as that of the inner. The tractors advance at a reasonable speed and the trailed loop of the chain progresses in a meandering fashion seldom striking more than two trees at one time and putting little strain on the tractors. It is essential to keep the chain moving over the ground at a reasonable pace as it is impact which knocks over the trees and thereby loosens and extracts the root system. The chain generally rolls freely over knocked-down trees. As the trees are knocked down, the main root system and laterals are extracted at the same time. In larger trees, the lateral roots extending in the direction of fall are only partially extracted, but such soil embedded roots are usually ripped out at windrowing. If no windrowing is prescribed, back chaining may further extract such roots.

An efficient unit for large-scale clearing of savanna woodland comprises two standard D-8 tractors, fitted with protective canopy, which pull a heavy anchor chain at least 90 m long. A third tractor fitted with a tree stinger assists in pushing over large trees. (Courtesy T.G. Allan)

Anchor chains are fitted with heavy swivels near the towing tractors to prevent the chain from kinking. (Courtesy T.G. Allan)

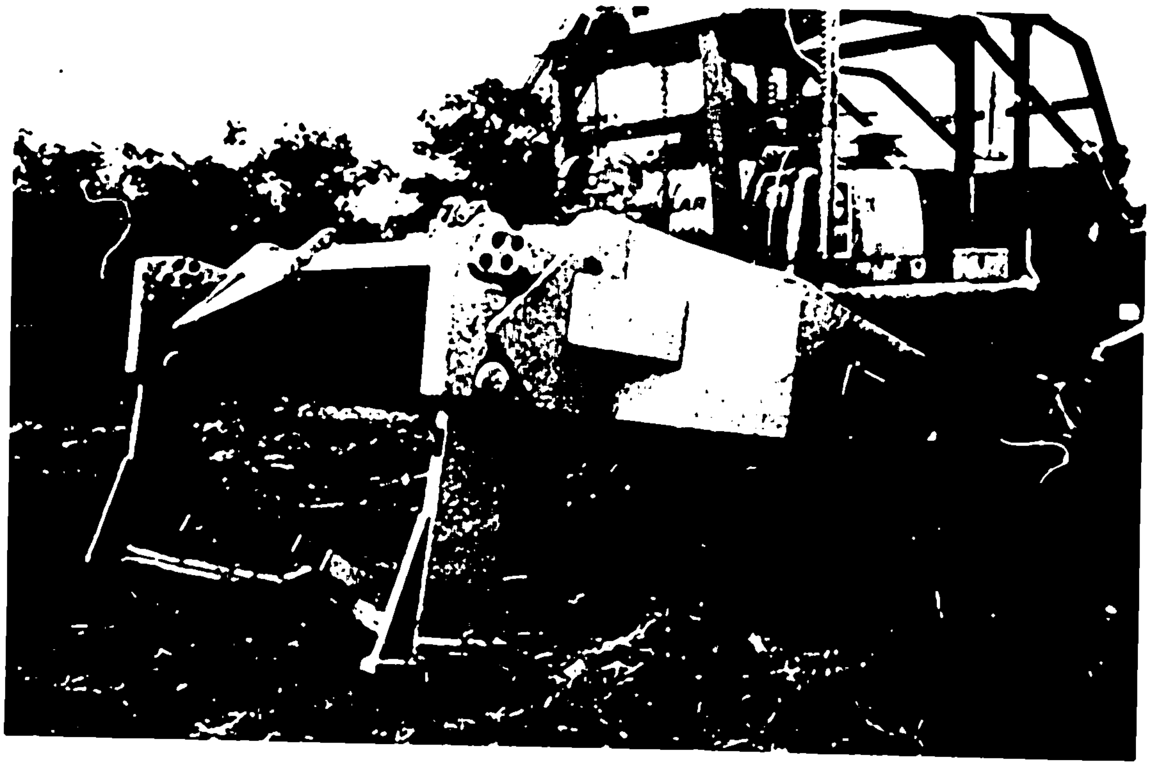
Tractor runs should be as long as possible, as turning time is largely unproductive. At the end of each run, the tractor unit is turned to return on a swath immediately adjacent to the previous run. In the turning process, the tractors reverse inner and outer positions giving an equable share of work to the tractor operators in that the inner station is generally the more difficult to operate.

Chaining is best suited for large-scale clearing of woodland or savanna type vegetation cover. It is not suitable for some types of thicket, however, where the trees tend to bend under the chain making extraction difficult; nor can it be used in dense forest or rain forest because visibility is so poor as to preclude the teamwork necessary for successful operation.

The chain size depends on the tractor power available and the type of vegetation, but the length should be at least two and a half times the height of the tallest trees. A 5 cm stud link 90 m long and weighing about 500 kg is suitable for light woodland. Heavier chains are available for heavier bush types.

Special Conditions

Areas covered with a coppice, shrub or thicket with full root systems below ground are often found near centres of population where forests have been felled for firewood. Such areas may be stumped manually or mechanically using a crawler tractor and rear-mounted root plough. The root plough is a V-shaped cutting blade which when drawn laterally through the soil floats at a predetermined depth and effectively severs all roots encountered. Behind a 180 hp crawler tractor the implement effectively operates at a depth of up to 42 cm. Vanes bring the severed roots to the surface with minimum soil disturbance. Providing the cutting edge is kept sharp, this is a most effective stumping and subsoiling tool. It can readily be used for clearing stumps from logged over areas.



A crawler tractor with rear-mounted root plough is effective in clearing thickets with extensive root systems. The plough is set into the soil at a predetermined depth where it severs the roots, which are then forced to the surface by special vanes. (Courtesy T.G. Allan)

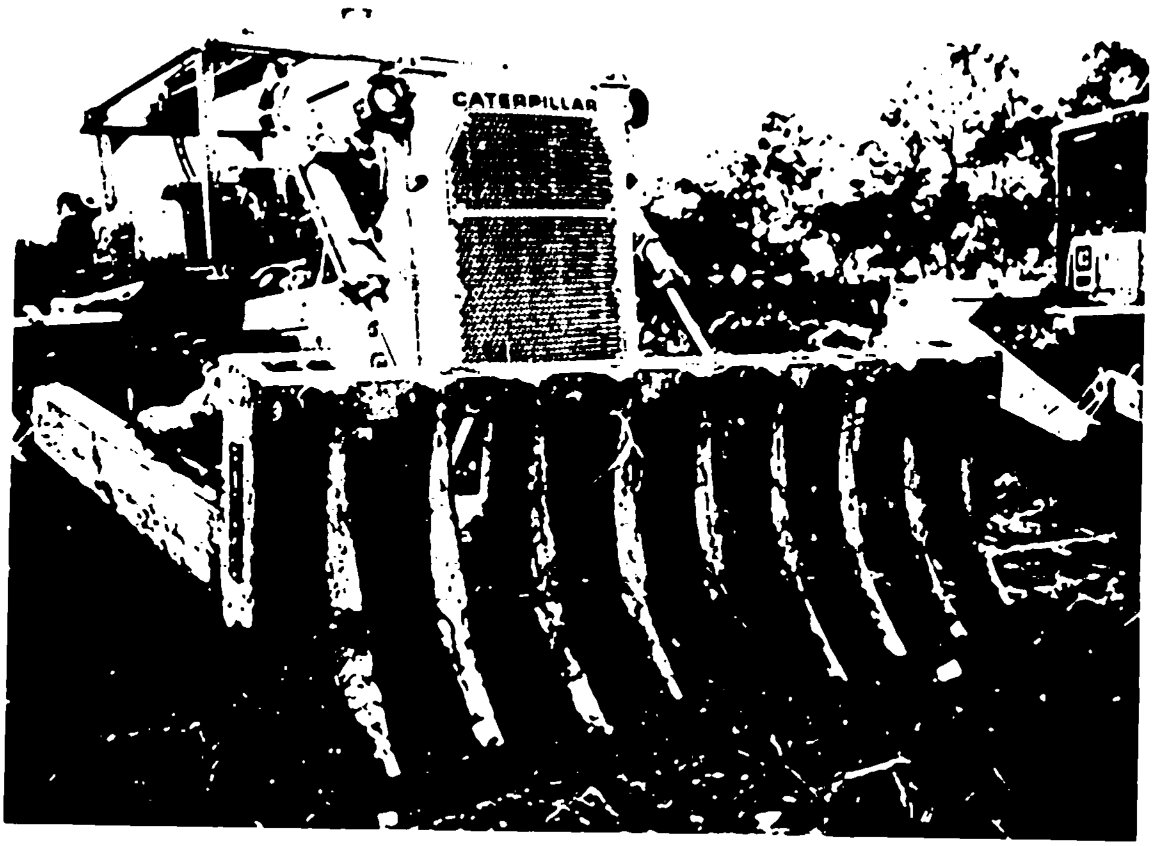
Windrowing

Following knockdown, it is necessary to dispose of the felled debris which litters the area. The same crawler tractors which were used for knockdown can be readily fitted with front-mounted rakes for mechanised windrowing and under some conditions heavy wheeled tractors may be used. On level terrain the heaps may be linear and parallel, while on slopes they may be sited on the contour. Windrowing may be done at any time during the year. In woodland it is convenient to site windrows 50 m apart. In this operation the front-end rake is lowered to ground level and all debris over a pass 25 m long and at right angles to the windrow is pushed onto the heap. The tractor then reverses 25 m and the raking process is repeated. This pushing of debris is then repeated from the other side of the windrow, leaving some 50 m between linear heaps. It is important to pack the windrows tightly and to include as little soil as possible. To allow access, 5 m gaps should be left in the windrows at 100 to 200 m intervals. In heavy forest with extensive debris, windrows might be only 25 m apart.

An alternative method of windrowing is to pile the debris around felled larger trees. This gives an irregular pattern of heaps and tends to take marginally longer than linear windrowing.

The general equipment for windrowing is a heavy track or wheel tractor, preferably with power-shift control and with a front-mounted rake. The reinforced teeth of the rake are set into the soil and in pushing forward most surface and some sub-surface woody vegetation is picked up while most of the soil falls between the rake teeth or tines, but even with careful operation, some topsoil is swept up with the woody debris and is deposited in or near the windrows.

A front-end rake mounted to a crawler tractor is used in the Ivory Coast to windrow rain forest debris following knockdown. (Courtesy T.G. Allan)




This front-mounted rake is a useful attachment for removing rocks and roots and for piling heavy brush. (Courtesy T.G. Allan)

## Cleaning Up

No matter how well knockdown and windrowing have been carried out, there is usually some debris or stumps remaining in the cleared area. Stumps left in the ground should be pegged or marked. Where there is not a great deal to clean up the usual practice is to use manual labour to gather the residual debris and put it in heaps or windrows and to deal likewise with any stumps it is necessary to excavate. Where there is extensive cleaning up, the operation may be mechanised using crawler tractors with rear or front mounted stump extractors or rakes. If there are holes where stumps have been excavated, these require filling and levelling.

## Burning of Windrows

When windrows or heaps have dried out, they should be burnt when conditions are suitable. The aim should be to burn as late in the dry season as possible. This may require protecting the heaps from incomplete, accidental burning earlier in the dry season. In rain forest areas where dry periods are short, it may be necessary to supplement or intensify the burn with oil fuel, and even then it may prove difficult to obtain a satisfactory total burn. The object is to have as fierce a fire as possible, and for this burning should take place during the day, preferably when there is a wind. The fire should be lit on the windward side of the windrow, where it will develop its own draught. When burning is incomplete it is advisable to have a crawler tractor with mounted rake standing by for repiling. When the fire has lost its main intensity, smouldering logs and stumps should be repiled to maintain the concentration of heat and combustible material.

Land Clearing Productivity and Choice of Equipment

Productivity data forms the basis of planning and selection of land clearing methods. Any general rate or cost of land clearing per hectare is of little value unless it is related to vegetation density and tractor power. Basal area of woody plants expressed as $m^2$/ha gives a reasonable assessment of forest density (although a factor may have to be applied for major height differences). Work in Nigeria (Allan, 1977) shows that:

1) in light savanna of 9 $m^2$/ha basal area, chaining productivity was 5.5 ha/hr for a clearing unit consisting of two 180 hp tractors; single tractor knockdown and windrowing using a 65 hp crawler tractor were 0.48 ha/hr and 0.49 ha/hr respectively; while hand-stumping and piling employed 69 man-days and 63 man-days/ha respectively;

2) in heavier savanna of 13 $m^2$/ha basal area, chaining productivity was 2.8 ha/hr using a clearing unit consisting of three 180 hp tractors (two for chaining and one for follow-up knockdown with a stinger); windrowing using a 180 hp crawler was 0.57 ha/hr while hand stumping and piling employed 134 man-days and 99 man-days/ha respectively.

This gives an indication of the range of productivities and of the type of options open to management. Translating these productivities into costs and taking manual operations as 100%, chaining costs in Nigerian savanna are of the order of 5%, single tractor knockdown around 10% and mechanised windrowing less than 12%. Similar data may be determined by trial for any plantation project. In Brasilian cerrado, the productivity of a chaining unit consisting of two 160 hp crawler tractors varied with woodland density from 0.5 to 8 ha/hr (Terâncio da Silva and Lourenco, 1977).

In rain forest in the Ivory Coast, the average tractor hours/ha for clearing using 180 to 220 hp heavy crawler tractors was 8 to 12; the lower figure was apportioned as 3 hours knockdown, 3 hours windrowing and 2 hours cleaning up (Allan, 1973a). No basal area figures were available.

In selecting methods of land clearing, the management options are manual, single tractor technique, chaining or a combination of these techniques. If one of the major objectives of the project is employment, then all of the clearing operations could be manual, whereas if minimizing cost is considered critical then mechanisation may be preferred. Unfortunately, deciding among the options available is seldom as simple or clear out as this. The first requirement is to determine the availability of resources. In relation to labour, are the required numbers available as and when required? For mechanised operations some of the essential considerations are:

1) past experience in mechanised work;

2) availability of equipment in the area or locality;

3) efficiency of the available equipment for the required operations;

4) availability of operators of the required skill and

5) existence of the required infrastructure, or possibility of establishing it readily.

Decisions require local data and local information. Scale of operation will greatly affect selection. Small-scale projects are most readily dealt with by manual clearing, while for large-scale projects mechanisation is usually more economic and efficient. Small-scale projects usually do not lend themselves to mechanisation because they do not allow for tractors to be operated for long enough periods to be cost efficient. For example, in general a mechanised land clearing unit can only be justified if the individual tractors can operate somewhere in the region of 1 250 hours or more per annum. Although there are no hard and fast rules relative to scale, something of the order of 4 000 ha/annum on a sustained basis would certainly constitute large scale. Such a programme could well be made up of a number of smaller areas or projects, or of combined forestry and agricultural programmes.

A chaining unit consisting of four 180 hp tractors and equipped with chain, rakes, tree stingers, root ploughs and other necessary equipment could deal with the following annual scale of work:

1) knockdown - 4 000 to 6 000 ha during a 4 months wet season;

2) windrow - 5 000 to 6 000 ha during a 6 months dry season and

3) major overhaul, maintenance and repairs - 2 months.

Any time not used as above could be used for cultivation, road making or other capital works.

Concerning selection of equipment, there is a considerable range of crawler tractors; the essential is to choose that model or models best suited to the planned operations. Land clearing can be dangerous and all tractors should have heavy duty cabs and other protection features. In the bush, bees and other insects can cause problems and protection against them may be required.

The main tractor attachments for land clearing are as follows:

tree stinger,
front-end rake,
combined rake and pusher bar or tree boom,
bulldozer blade,
K.G. blade,
V-type blade,
rippers,
root plough,
anchor chain,
rolling chopper,
stumpers,
towed root rake,
land conditioner.

Selection of tractors and matching equipment is an important management decision. The careful matching of machines and equipment to local conditions, for example, can easily effect savings of more than 50% of total mechanisation costs, as compared to the use of less suited or poorly matched machinery.

Serviceability is also a principal criterion, and that local agency providing the better back-up service and supply of spares should be given preferential consideration. All attachments must be matched to the power units held. As there is a considerable range of equipment, specifications need to be carefully compiled and it is often advisable to obtain specialist advice.

## Plantation Layout

Laying out is an operation in which compartments, blocks, roads, rides and firebreaks are surveyed and delineated on the ground. As the design of plantation layout is a major planning consideration it is also discussed in Chapter 6. The main mechanized aspects of the operation are the cultivation of firebreaks and the formation, draining and paving of roads. Firebreaks are readily cultivated using the same crawler tractors and heavy offset disc harrow ploughs as for pioneer ploughing. The land clearing crawler tractors with bulldozer blades can be used for putting in road lines and cuts, and such lines when provided with bridges and culverts will serve as class 3 roads or planting tracks. Road formation and the provision of all-weather surfacing of the higher specification class 1 and 2 roads will require additional mechanisation in the form of road graders, front-end loaders and tipper trucks. More complete notes on the establishment of plantation roads are given in Appendix B.

## Mechanized Pre-planting Cultivation

The main purpose of removing roots and woody debris from selected sites is to allow soil cultivation before and after planting. Such clearing and cultivation creates site conditions particularly favourable to the plantation tree crop by eliminating or reducing vegetative competition and by increasing percolation, which can reduce the moisture loss from the soil. These favourable water budget features are particularly important in areas of restricted or seasonal rainfall. The need to reduce competition applies also on certain dense or tall grassland sites where failure to cultivate results in inadequate plantation establishment.

Cultivation may be partial as in strip cultivation and ridge ploughing, total as in clean cultivation or supplementary as in ripping or subsoiling.

### Strip Cultivation

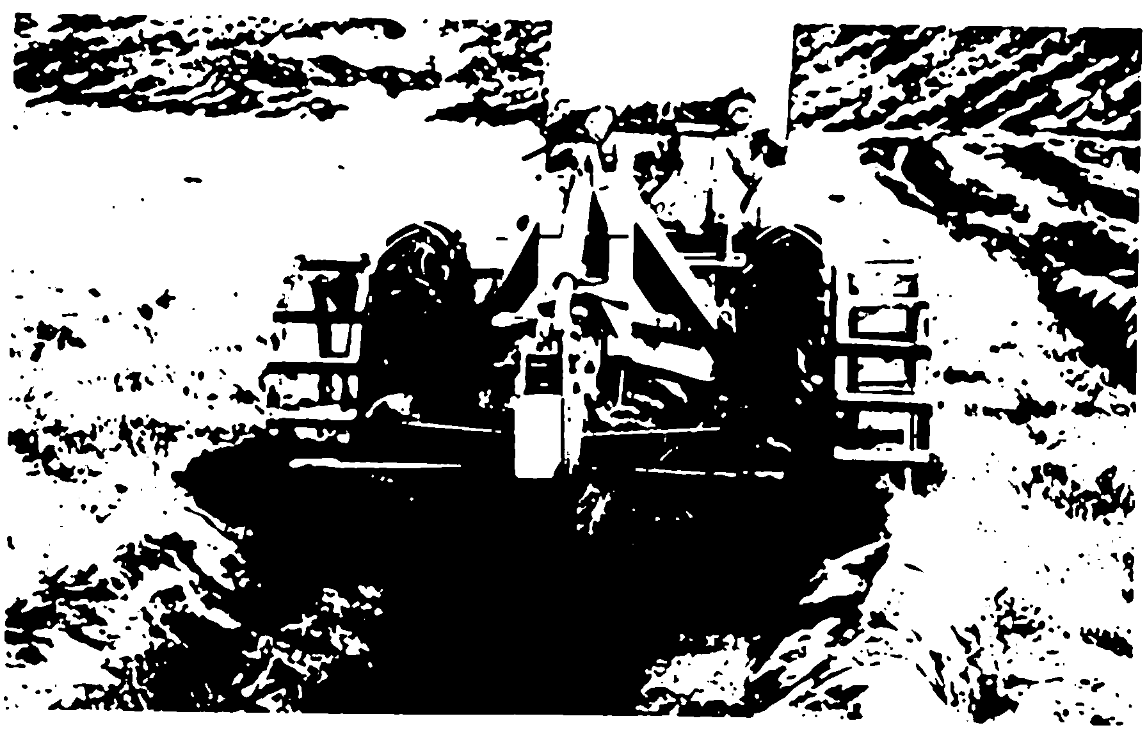
Under certain site conditions where some species require only local weeding to allow adequate growth and development, it may be enough to cultivate only a narrow band (1 to 2 m wide) along the planting line, sufficient to give the trees freedom from competition in the initial period after planting. Often this can be achieved by the harrowing effect of a mechanical tree planting machine (see for example page 63). The planting stock used in these conditions must be vigorous. Where necessary, further cultivation would take the form of a supplementary manual operation. Strip cultivation by opening up only a part of the site may be of particular importance where there is a high risk of erosion.

Strip ploughing along contour lines in gentle terrain is used extensively in establishing Pinus patula on the Viphya Plateau in Malawi. A reversible 3-disc plough drawn by a 70 hp wheeled tractor is used to breakup the short montane grass cover. Initial cultivation is to depths of less than 30 cm; a subsequent harrowing improves the soil tilth. On shallower soils over an indurated, weathered quartzite layer, where plough penetration is slight, subsoiling in the direction of the planting line is necessary. On sites free from stones, a 1.55 m wide rotavator is sometimes used, which can cultivate to 12.5 cm depth provided grass is previously burnt off. Mattock pitting is necessary on rougher and steeper sites, but records show that it is almost twice as costly as strip ploughing.

### Ridge or Turf Ploughing

Ridge ploughing is used extensively in the United Kingdom and other upland temperate areas, particularly on wet soils and peatland bogs. A specialized mould-board plough, generally drawn by a heavy crawler tractor, is used to turn over a broad turf ridge creating a clean deep furrow which helps to drain the site. On difficult sites where the peat is deep, the furrows are spaced at intervals of 1.5 to 1.8 m. On better, less wet sites, furrows are spaced at 5.0 to 6.5 m apart. The turves are then manually cut into squares which are laid out at the required plant spacing. At planting, tree seedlings are planted into the turves.

Grassland sites of gentle terrain on the Viphya Plateau in Malawi are prepared for planting by ploughing contour strips 1.2 m wide with a mechanical disc plough. (Courtesy D.A. Harcharik)



Drainage of heavy wet sites in the United Kingdom can be improved by ploughing with a mould-board plough. That shown here is used with a standard parkgate carriage towed by a Fiat 100 c tractor. (Courtesy D.A. Thompson)

On drier moorland sites, especially Calluna heath lands, the problem is to reduce shrub competition and soil compaction and to break the hardpan when present. Single furrows are made at the required plant spacing using either single mould-board plough or a special tine plough. At planting, seedlings are notched either into the furrow bottom or into the side of the furrow and ridge.

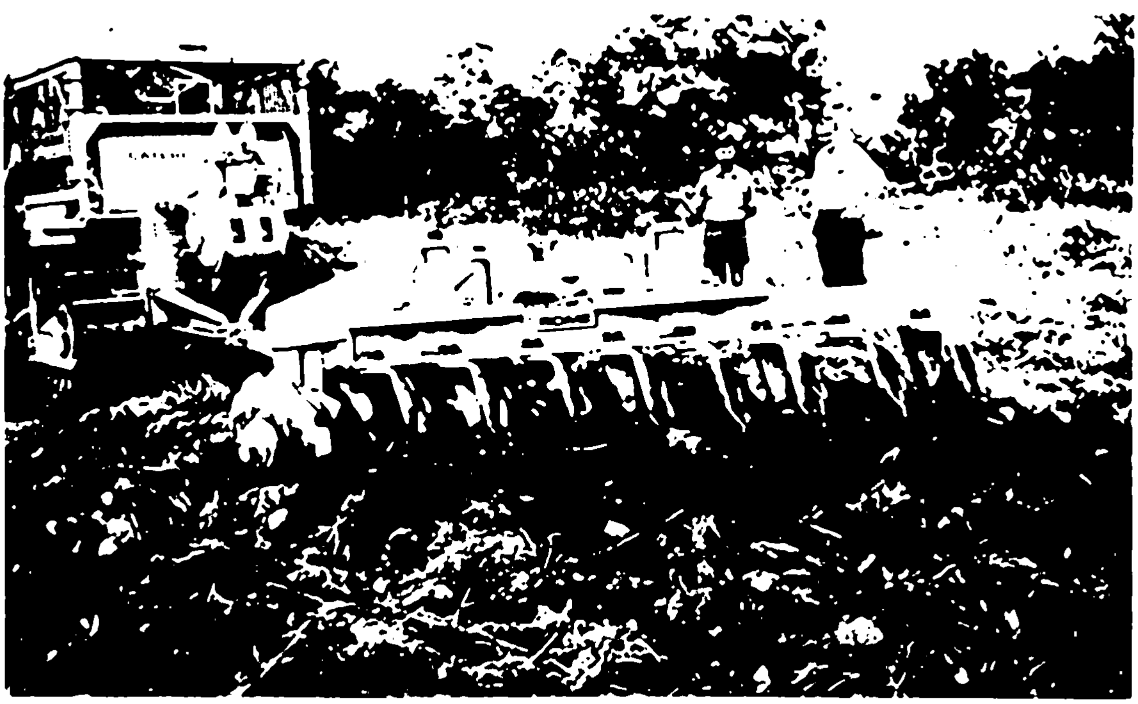
Clean Cultivation

Clean cultivation of the site prior to planting is required where subsequent weeding is to be done mechanically. The practice is common, for example, in regions with a long dry season where clean weeding is necessary in order to prevent grass from competing excessively with the tree crop for limited soil moisture. Clean cultivation often comprises two main operations: 1) pioneer ploughing and 2) pre-planting harrowing.

1. Pioneer ploughing

The objective of pioneer ploughing is to break in the soil for the first time and plough in all weeds or vegetation. This is essentially a rough operation and the cultivation need not be to the same precision or standard as is required for agriculture. The ploughing should generally be done when the soil is moist but not saturated and to a depth in excess of that reached by lighter implements used in subsequent weeding operations; over 20 cm is usually required. Penetration is often difficult in dry soils.

The operation may be effectively done by a crawler tractor with a matched heavy duty disc harrow plough having heavy steel discs of over 75 cm diameter. This offset harrow plough gives a deep penetration of over 30 cm under ideal conditions and, although it is a harrowing rather than a plough action, in practice has given adequate results for subsequent plantation operations. Although these heavy duty harrows are sufficiently strong to shatter most stumps, and can therefore be used to plough unstumped land, such rough operation is likely to reduce the life of the equipment and increase the cost of operation.



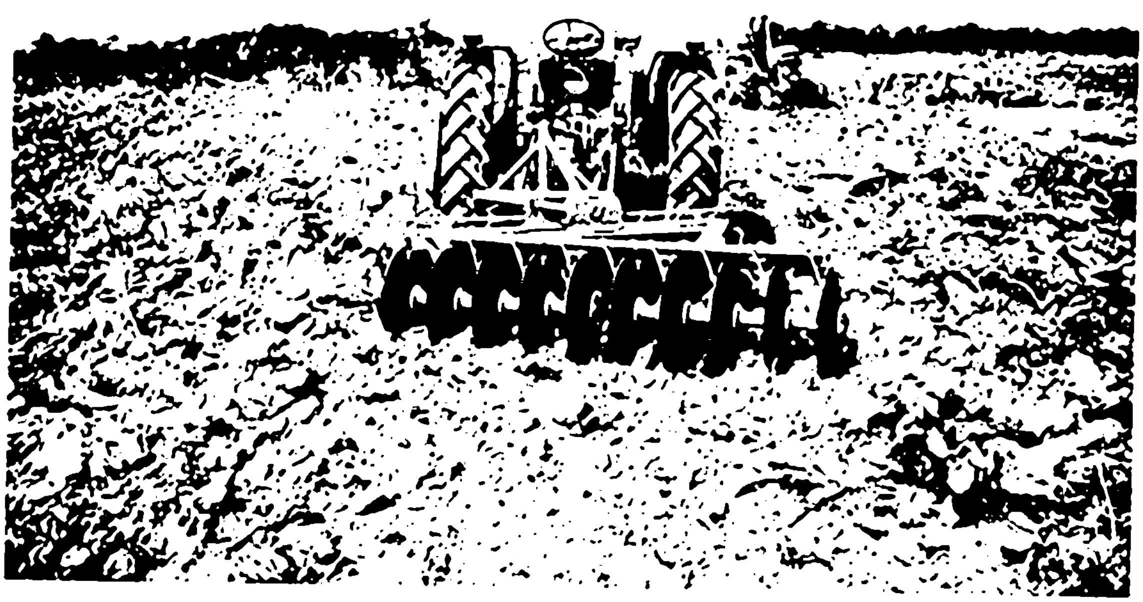
The heavy duty offset disc harrow plough towed by a crawler tractor is used for pioneer ploughing. (Courtesy T.G. Allan)

Pioneer ploughing can also be undertaken by a medium wheeled tractor with a mounted disc plough. The cultivation is good, but generally to a shallower depth than the harrow plough. On difficult sites, the disc plough is less robust than the heavy harrow.

On sloping ground in Turkey, the Clark double mouldboard tine plough is used for pioneer ploughing on the contour (Deveria, 1977). This subsoiling plough produces a mound and furrow effect, with a downside mound approximately 1.5 m wide and 0.5 m high and the upside trench 0.3 m deep and 0.5 m wide. The trench has a subsoiling groove extending for a further 0.3 m depth.

2. Pre-planting harrowing

Pre-planting harrowing usually takes place just prior to planting. The objective is to breakup soil clods and create a tilth, to level the soil surface, to bury any weed growth and to have the land in a clean state for planting. Land free of weeds, with friable soil cultivated to at least 15 cm considerably facilitates planting and subsequent mechanized weeding. The operation is generally undertaken by a medium wheeled tractor with a mounted agricultural type disc harrow. The operation should be in the same direction as ploughing. If justified by the quantity of work, a wide heavy duty disc harrow may be used specifically for this work, or alternatively, fuller use may be made of smaller weeding harrows. Cultivation may also be done by a rotavator, or rotary hoe, but this implement requires greater skill to operate. There are also a number of large heavy harrows that may be used with crawler tractors, but implements such as the pulverising harrow produce so fine a tilth that great care is required in their use, particularly in areas liable to erosion.



Following ploughing, tilth can be improved by pre-planting harrowing with an offset disc harrow. A wheeled tractor is a suitable power unit for this operation. (Courtesy T.G. Allan)

In parts of the southeastern United States and other areas where there is a high water table during much of the year, bedding, or mounding, of the planting sites facilitates planting and results in better tree growth by improving drainage and microsite environment. The operation is done with a disc bedding harrow designed to concentrate surface soil, litter and vegetative debris into raised beds 15 - 30 cm high and about 1.2 m wide at the base. A rolling hourglass-shaped drum with a centre-mounted coulter is often used behind the harrow to shape and pack the bed. The site must be sufficiently free from logging debris and vegetation for a well-shaped bed to be formed. Beds should be oriented so as to channel runoff into ditches and natural water courses and, except in flat terrain, they should follow the contour. The operation is not suitable where seedlings would suffer from seasonal drought (Haines et al., 1975 and Balmer et al., 1976).

Subsoiling or Ripping

On shallow soils overlying weathered rock, on compacted soils or on soils with an underlying hardpan where root growth is restricted, water infiltration and root penetration can often be improved by subsoiling, or ripping. The operation involves tillage of the subsurface soil, without inversion, by subsoiling tines or rippers mounted behind wheeled or crawler tractors. Subsoilers can be either of the single-tooth or multiple-tooth type. With the appropriate tractor and equipment, subsoiling to depths in excess of one metre is possible, but shallower operation to about 60 - 70 cm is more common. Subsoiling usually follows normal ploughing, and on sloping land it should be done along the contour. In Cuba (Massen, 1973) it was found that subsoiling in the dry season gave much better lateral shattering than when carried out in wet soil and that the general effect was highly beneficial to subsequent planting.

Indurated soil layers can be broken by subsoiling to improve water infiltration and seedling root penetration. The soil surface is not turned. (Courtesy T.G. Allan)


Surface drainage and microsite conditions can be improved by using a bedding harrow and roller to form raised beds for planting. (Courtesy T.G. Allan)

## Cultivation Productivity and Choice of Equipment

Recorded practical data on ploughing and harrowing indicate productivities of the following order:

| Operation and Equipment | Output in ha/hr | |
|---|---|---|
| Ploughing | Tropical 1/ | Temperate 2/ |
| 65 hp wheeled tractor with mounted 3 disc plough | 0.35 to 0.40 | 0.46 to 0.56 |
| 80 - 100 hp crawler tractor with matched heavy duty harrow plough | 0.5 to 0.75 | - |
| Pre-planting harrowing | | |
| 65 hp wheeled tractor with 2 m disc harrow | 0.5 to 0.9 | 1.0 to 1.2 |
| 65 hp wheeled tractor with 3 m disc harrow | 0.9 to 1.1 | 1.1 to 1.7 |
| 80 - 100 hp crawler tractor with pulverising harrow | 1.0 to 1.2 | - |

1/ Figures for the tropics are based on practical field trials in east and west Africa.

2/ Figures for temperate regions are based on Culpin (1975) for agricultural land.

Note: Productivity is a factor of so many variables such as state of equipment, operator efficiency, soil type and condition that figures quoted are only indicative. Tropical outputs tend to be less because they refer to pioneer operations under rough conditions whereas the temperate figures are based on agricultural practice.

There is an extensive range of tractors and cultivation implements adequate for plantation cultivation; the main choice is between wheeled or crawler units. In relation to ploughing, wheeled tractor units tend to be marginally more cost efficient, but heavy duty crawler units cultivate to greater depths and eradicate hidden roots and other movable obstructions. As for land clearing equipment, decisions on cultivation equipment should be based on local experience and knowledge and where there are gaps, data may be obtained from trials or from projects operating under similar conditions.

If timeliness is considered the main factor in pre-planting cultivation, then those units giving the greatest productivity should be preferred. Efficiency and usage can be important, however, and it may be possible to reduce costs by fuller use of heavy clearing equipment in cultivation or by increasing the use of wheeled tractor weeding units in the cultivation phase.

Sequence of Land Preparation Operations

As already noted, climate considerably affects land preparation operations. The following is an outline sequence of operations for an area with a 6-month dry season, assuming that land cleared during one wet season will be planted at the beginning of the next. The sequence can be adapted to other climatic patterns and may even be extended over two years, but any longer period runs into regrowth or weed problems.

| Season | Operation |
| --- | --- |
| Start of rains (after 100 mm recorded), year 0 | Commence knockdown or stumping. Windrowing, cleaning-up and ploughing between windrows may also start. |
| 20 days after end of rains, year 0 | Stop knockdown or stumping. Complete windrowing. Clean-up between windrows. |
| Before end of dry season, year 0 | Burn-off windrows. |
| Beginning of rains, year 1 | Complete ploughing. Harrow prior to planting. |
| Start of rains (after 100 mm recorded), year 1 | Commence planting. Commence knockdown and ploughing for year 2 planting area. |

DRAUGHT ANIMALS

For small-scale plantations in light soils, trials in northern Nigeria employing oxen with matched ploughs and spring tine harrows have indicated that such units can be operated practically and economically for pioneer ploughing and pre-planting harrowing (Allan, 1973b). Such units require a large training input, however, and are seldom used in forestry.

Cultivation using oxen with matched ploughs and spring tine harrows is a feasible and economic possibility for small-scale plantation development on selected sites. (Courtesy T.G. Allan)

## CHEMICAL METHODS

The main use of chemicals in site preparation is to kill grass, shrubs, trees or stumps. Under certain conditions chemical application alone may give adequate site preparation, but more frequently chemicals are used in conjunction with or supplementary to other land clearing techniques. Areas of grass, for example, may be killed by herbicides so that it can be burnt off while surrounding vegetation remains green. Chemicals may also be used to kill regrowth following felling, stumping or chopping.

In addition to their use in site preparation, chemicals are also widely used to control weeds during plantation establishment. For post-planting weeding it is important to apply the chemical in such a way and at such a season as to minimize the risk of damage to the plantation trees.

Various terms are used to refer to the chemicals used in site preparation and tending. A "phytocide" is a general term for any chemical preparation used to kill or inhibit the growth of plants. It includes "arboricides", "silvicides" and brushkillers, which are used against trees and other woody plants, "herbicides", which strictly speaking are used against herbs, and "fungicides", which are directed against fungi. The term herbicide, however, is now in common usage to refer to all chemical substances used for killing plants, especially weeds, regardless of whether they are herbaceous or woody, and is used in this sense in this publication.

Herbicides are usually marketed under proprietory names, and the same chemical compound may have different names in different parts of the world. Some are toxic to all vegetation while others are selective, for example, affecting only dicotyledonous plants, only grasses, or only certain genera.

Herbicides act in the following ways in killing plants:

1) The "contact" herbicides poison the parts of the plants coming in contact with the chemical.

2) The "translocation" chemicals are absorbed either through roots, foliage or stems and are translocated via the xylem or phloem.

3) The "soil acting" or pre-emergence chemicals are toxic in the soil to germinating seeds.

4) The "total" weedkillers, like sodium chlorate, kill all vegetation when applied to the soil. The soil remains poisoned for several months after application.

The effectiveness of herbicides is dependent on a number of variables such as season of application, plant species and size, forest structure, soil moisture and weather. Herbicide applications made during the growing season are generally more successful. Late spring or early summer when root reserves are low are particularly favourable periods. In general, large trees are harder to kill than small ones, and the more vigorous the tree the more difficult it is to kill. Trees under one year old are particularly susceptible to herbicides. Forest stands of two or more levels will require either two different treatments or two applications of the same treatment, and particularly dense stands may preclude the successful use of herbicides. Soil moisture has an effect on the success of translocated herbicides. Although a low or deficient supply of soil water does not affect absorption, it can hinder translocation in hardwoods. Rainfall can have adverse effects by washing off sprays from bark and foliage, and high winds make broadcast applications ineffective or spotty. Moderately warm temperatures and high humidity are considered favourable conditions for spraying, but high temperatures can physically effect the herbicide, as even low volatile esters start to volatilize above 32°C. These represent only a few of the possible variants affecting herbicide application.

In some countries considerable work has been done on the types and uses of herbicides, and rates and methods of application can be laid down for specific vegetative types. In many other areas work is at the experimental stage and much remains to be done in developing optimum and safe techniques. As a consequence of the many variables in herbicide application and the toxic side-effects of many of the chemicals, there is an obvious need for detailed study and research before applying such techniques in new areas. A useful "Review of the Ecological Effect of Herbicide Usage in Forestry" has been compiled by Kimmins (1975) which contains an extensive list of references.

## Principal Herbicides Used in Forestry

The following sections give a summary description of the main herbicides which have found application in forestry. The list is far from complete; for a more comprehensive account of the type of herbicides and more detailed information on their use, the reader should consult one of many weed control handbooks, such as Crafts (1975), Fryer and Evans (1970) and Fryer and Makepeace (1972).

### Herbicides for the Control of Woody and Herbaceous Weeds

#### 2,4,5-T (2,4,5-trichlorophenoxyacetic acid)

This is a translocation herbicide, particularly effective against woody broadleaved species. Most conifers are resistant in the dormant season, but some species such as the larches and some pines (e.g. *Pinus radiata*) are susceptible.

Various forms of 2,4,5-T are available; most common are the: 1) amine salts, 2) unformulated esters and 3) formulated or emulsifiable esters). The amines come in liquid form and are available as either water or oil soluble for foliar spraying. The unformulated esters are suitable for use only in oil (itself toxic to trees) which restricts their use to the control of vegetation before the forest crop is planted, or to applications to stumps, stems and frill girdles. The formulated or emulsifiable 2,4,5-T esters are prepared for emulsification in water. These are normally diluted in water for spraying and, though more expensive, have a more widespread use.

Most of the common broadleaved woody species, in all climatic regions, are susceptible to 2,4,5-T foliar spraying, some more than others, and this has become one of the most widely tried and used herbicides. In the temperate zones, the genera most susceptible are *Alnus*, *Aesculus*, *Acer*, *Betula*, *Corylus*, *Carpinus*, *Populus*, *Prunus*, *Salix*, *Sambucus* and *Ulex*. Resistant genera are *Ilex*, *Ligustrum* and *Rhododendron*. *Quercus* spp., though partially resistant to foliar sprays, can be controlled by bark spraying. Often a related phenoxy herbicide called silvex 2(2,4,5-trichlorophenoxy) propionic acid, is more effective than 2,4,5-T in controlling certain woody plants, particularly oaks.

In the United States 2,4,5-T has been used extensively for site preparation and for weeding. Rates of application are in the order of:

| Method | Application Rate |
|---|---|
| Foliage sprays | 2.5 to 5.0 kg acid equivalent (a.e.) per ha |
| Shoot sprays | 5 to 7.5 kg a.e. per ha |
| Basal bark and cut stump treatments | 6 to 8 kg a.e. per 450 litre of oil |

In Australia 2,4,5-T has been reported as effective in controlling eucalypt coppice regrowth in pine plantations.

2,4-D (2,4-dichlorophenoxyacetic acid)

This is a translocation herbicide useful for the control of a wide variety of broadleaved herbaceous weeds. It is available in the same forms as 2,4,5-T. In forestry, 2,4-D has found a particular use in eliminating heathers (e.g. species of Calluna, Erica and Rubus). For this purpose, the low volatile nonyl ester of 2,4-D containing 500 g acid per litre is suitable; prepared for emulsification in water it can be used as a foliar spray. Young conifer plants are susceptible to damage by 2,4-D in the growing season. The amine salt formulation is used undiluted for application to cuts made in the bark of trees.

The combination of 2,4-D and 2,4,5-T emulsifiable esters forms a dual purpose spray for the control of broadleaved vegetation containing both woody and herbaceous species. Applications are usually in the region of 2 to 5 kg/ha a.e., but difficult or persistent species may require special heavy applications.

Ammonium Sulphamate (AMS, or Ammate)

This is a highly soluble, crystalline chemical which kills many woody species. Its main use is for application to cut stumps or the stems of 2,4,5-T resistant species. A solution of 400 g of AMS per litre of water is normally used, but the application of small amounts of the chemical in crystalline form direct to the freshly cut stump or frill-girdle is also effective. It can also be applied as a foliar spray. Areas sprayed or misted with AMS should not be planted until 12 weeks have elapsed after treatment.

This chemical rapidly corrodes all metal and should therefore be stored only in plastic containers; spraying equipment should be thoroughly cleaned immediately after use.

Sodium Arsenite

This highly toxic chemical has found wide use throughout the tropics for frill-girdling unwanted stems which are too large to be economically cut and removed. Frill-girdling with sodium arsenite is standard practice, particularly in the method of line-planting in tropical rain forest areas. In the Solomon Islands, for example, this method is normally used to poison over-wood stems, using an average of 170 g of sodium arsenite per ha. Its great mammalian toxicity, however, constitutes a serious risk for personnel handling it, and in many countries its use as a herbicide is prohibited. It is dangerous to cattle or game, due to its attraction as a salt lick.

Pentachlorophenol (PCP)

This chemical has been used in Papua New Guinea, (obtainable as a 15% concentrate) for foliage sprays killing annual broadleaved and grass weeds both in nurseries and in the field.

Picloram (4-amino-3,5,6-trichloropicolinic acid)

Picloram, or tordon, is a postemergence, translocated herbicide extremely effective against woody plants and particularly useful in preventing coppice growth. Most grasses are tolerant. It has been used in southwestern Australia for killing eucalypt growth in plantations of Pinus radiata, which is less susceptible to picloram than to 2,4,5-T. It is also used in controlling brush along rights-of-way, roadsides and firebreaks and can be obtained as a water-soluble material for aerial application or in pellets for hand or machine application.

### Triazines

The triazines, including simazine and atrazine, act on emerging seedlings by interfering with processes associated with photosynthesis. As they lack phloem mobility, they are applied to the soil where they are readily absorbed by roots and translocated to the foliage via the xylem. They are generally most effective with good soil preparation.

Atrazine is probably the triazine of widest agricultural use. In forestry it is used as a preemergence herbicide in nurseries and plantations.

Simazine is also a preemergence herbicide but is more persistent in soils than atrazine. Usually marketed as a wettable powder containing 50% or 80% simazine, it is generally applied to the soil before planting. In the United States simazine has been successful in controlling grass and herbaceous weeds when sprayed along the planting lines in early spring prior to planting with Scots pine. It is, however, most widely used in forest nurseries for weed control in transplant beds.

### Sodium Chlorate

This is a "total" herbicide applied to the soil for killing perennial vegetation on roads, tracks and firebreaks and in depots and store yards etc. The soil remains effectively poisoned for many months, and in the case of some species for a year or more.

## Herbicides Specifically for the Control of Grasses

Competition by perennial grasses in young plantations is a widespread problem, often retarding crop growth and giving rise to high weeding costs. Two chemical sprays have so far proved satisfactory: dalapon and paraquat.

### Dalapon (Dowpon)

Dalapon is a translocated herbicide affecting only monocotyledons. Some grass species are more susceptible than others: *Agrostis*, *Deschampsia*, *Molinia* and *Nardus* species are very sensitive, *Agropyron* and *Holcus* species less so. For pre-planting control of grassy sites, a solution of 8 to 17 kg dalapon in 350 - 450 litres of water per ha is sprayed not more than six weeks and not less than three weeks before planting. This enables the crop to be planted into newly killed grass.

In planted areas dalapon can be effective in controlling grass between the rows of young conifers at an application rate of 11 kg dalapon per ha without damage to the conifers, provided that spraying is restricted to periods when the trees are dormant. Control spraying should be repeated at intervals depending on the vigour of the regrowth.

Dalapon is one of the few chemicals which can be used to control monocotyledonous water plants in ditches, water courses and ponds without endangering fish or other forms of life in the water. Its effectiveness against weeds, sedges and rushes in wet sites is often improved by mixing with 2,2,3-trichloroproprionic acid.

### Paraquat (Gramoxone)

This is one of the dipyridylium group of chemicals and acts by translocation. It is quickly absorbed and is extremely rapid in action against nearly all green growth. Paraquat is particularly effective in killing annual grasses and fibrous-rooted or stoloniferous species. It can defoliate woody species, but rarely kills them, so its use is mainly confined to sites where grass or herbaceous weeds are troublesome. The chemical is generally inactivated on contact with the soil so planting can follow shortly after spray treatment.

Paraquat can be used in young plantations, provided that the plants are well screened from the spray. It is most effective in early spring before weed growth has grown taller than about 20 - 25 cm.

The rate of application is normally at 11 litres of gramoxone in 550 litres of water per hectare treated. The chemical is highly poisonous and requires care in handling.

## Methods of Herbicide Application

The main methods of applying herbicides are by apparatus carried by an operator, by machine powered equipment or by aerial application. The most common equipment consists of a range of knapsack sprayers, which are carried on the operator's back and, employing compression, emit a fine spray through a jet. The direction, timing and type of spray droplets can be controlled by the operator. Other related types of applicators include motorized knapsack mist blowers for low volume application of liquids and a similar item designed for applying granular herbicides.

Ultra low volume (U.L.V.) sprays are a more recent development which spread the herbicide by producing large numbers of relatively uniform-sized droplets which are dispersed evenly over the area by a fan, or by gravity and the natural movement of the air. The basic applicator consists of a plastic tube which acts as battery holder and a handle for the applicator head. The head contains a two-tier electric powered disc onto which the herbicide is fed from a one litre reservoir. The disc has a serrated edge and when rotated at high speed (up to 6 000 revolutions per second) produces an extremely fine dispersal. The main advantage of the U.L.V. applicator is that the same dispersal of active ingredient can be achieved with 2 to 10 litres of concentrate as would be attained with 100 to 700 litres of diluted herbicide using conventional sprayers. In using the U.L.V. technique, the saving in transport of dilutent is obvious, which offers new opportunities in arid areas where water availability is a constraint to using conventional spraying. The use of U.L.V. techniques is being developed in forestry, and a range of investigations is being carried out in a number of countries.

There are a number of tools which are used to inject herbicides into the tissues of undesirable trees or shrubs. Such equipment usually comprises an axe or chisel head through which herbicide is injected from a reservoir when the cutting edge is applied to the cambium. These tools offer a more sophisticated approach to frill girdling which can be supplemented by spray or paint brush application of herbicide if required.

A range of equipment for larger scale operation has been designed for tractor mounted or towed operation. The types of equipment are live reel sprayers, mist blowers and granule applicators. Work on tractor mounted U.L.V. apparatus is under research and development. Aerial application generally from fixed-wing aircraft, is perhaps the best method of covering large areas quickly. The big risk in aerial application, however, is drift of herbicide onto adjacent lands, water courses or crops, and this factor severely limits its use.

Many of the herbicides have harmful or irritant effects on operators if protective or safety measures are not taken. It is essential, therefore, that the possible effects of any chemical should be fully studied before use, and that any recommended or legal safety measures be applied. Using any of the herbicides requires the wearing of protective clothing, often including gloves and face shields. Such requirements have limited the use of herbicides in warm or hot climates.

## Features of Herbicide Vegetation Control

One of the major advantages of successful chemical site preparation is that the effect can be longer lasting than that of other methods, and when so effective the problem of unwanted regrowth is diminished. In areas liable to erosion, the killed vegetation very often acts as a mulch, reducing the rate of erosion while presenting no competition to the plantation crop, but in drier areas such dead matter contributes to the fire hazard. Chemical clearing can be used in terrain too difficult for mechanized methods. Although chemical clearing may often be more costly than other methods, frill-girdling and basal spraying techniques of killing unwanted stems have been developed for economic use in a number of countries. A major disadvantage is that the need to carry or have large quantities of dilutents available on sites has restricted the use and range of ordinary sprayers. Fortunately the development of ultra low volume applications is likely to diminish this problem.

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# CHAPTER 2

# DIRECT SOWING

## GENERAL CONSIDERATIONS

Once the area to be afforested has been prepared, the forest crop is introduced either by sowing the tree seeds directly or by planting forest nursery stock, stumps, wildlings or cuttings. The choice of whether to sow or to plant depends on a number of factors. The factors favouring the choice of direct sowing are:

1) Cost. Direct sowing, when successful, is usually cheaper than planting: it avoids the cost of raising nursery plants and generally is a less costly operation than planting. Costs can be further reduced if aerial seeding methods are possible, especially in areas of difficult access.

2) Abundance of cheap seed. Direct seeding requires much greater quantities of seeds to secure a reasonably full stocking than is required by planting nursery stock. A critical factor, therefore, is the possibility of procuring large quantities of seed easily, and at low cost, as is often the case when local species are used.

3) Seeds which do not grow well in nurseries. The seeds of certain species (e.g. *Pinus roxburghii* of the Himalayas) are difficult to raise in nurseries, and direct sowing gives better results. Plants of most species suffer from the shock of being transferred from the nursery to the planting site, and in some cases direct sowing might give better results. Plants resulting from direct sowing, for example, particularly in fine textured soils, often have better root development than nursery-grown seedlings field planted in notches where root development is often restricted to the plane of the planting slit.

4) Seeds of easily established fast-growing species, or of species growing on sites where competing vegetation is negligible. Direct sowing is preferred where seedlings grow fast enough to survive and outstrip competing vegetation on the site, making a prolonged period of tending and weeding unnecessary; otherwise the financial advantage of sowing is lost. Direct sowing from the air has been employed very successfully

for seeding Pinus radiata on short grass sites in parts of New Zealand and for various other pines in the southern U.S.A. as well as in the prairie provinces of Canada. In Finland direct seeding of Scots pine on some types of recently drained peat bogs without other soil preparation is a common practice (the wet surface offers a good germination substrate, the competing vegetation is less abundant and pests and diseases are more scarce than on mineral soils).

5) Adequate germination. The species selected must give reliable and forecastable germination under field conditions. Often species with large seeds are preferred because they give large seedlings which resist adverse environmental conditions better than smaller ones.

The main disadvantages of direct sowing are:

1) The relatively large quantities of seed needed to offset losses from seed-eating birds, rodents and insects, as well as losses due to climate, soil and competing weed growth. Other sources of seedling loss are frost, which freezes seedlings or lifts them out of the ground (i.e. frost heaving), and animals that browse or trample seedlings. If the cost of obtaining seed is high, for example, when using imported seed, or seed of special provenances or from seed orchards, or when it is difficult to obtain adequate supplies, it is often more economical and efficient to raise nursery stock.

2) The irregular stocking, especially with broadcast sowing and, therefore, the less efficient use of the growing space, compared with planting methods. Too dense stocking will require an early cleaning or reduction operation. This was the case in New Zealand where such additional work reduced much of the cost benefit of direct sowing. On the other hand, continuous changes in the site (e.g. soil fertility) are utilized more efficiently when using direct sowing.

The economies possible by sowing from the air have encouraged research into methods of embedding the seed in pellets containing anti-pest chemicals and materials designed to aid germination. Successful developments in these fields have made direct sowing a commonly used and practical afforestation method in many parts of the world. Nonetheless, the trend is towards planting which, though more costly, is generally more certain and allows greater control over the crop.

## PRE-SOWING TREATMENT OF THE SEED

Some seeds are ready for sowing as soon as they are collected from the parent tree; others pass through a dormant stage during which the embryo completes its development. Often a pre-treatment is used to hasten germination, or to obtain a more even germination. The types of treatment vary with the different types of dormancy of tree seeds; the main types of dormancy are:

1) Exogenous dormancy, connected with the properties of the pericarp or the seed coat (i.e. mechanical, physical or chemical);

2) Endogenous dormancy, determined by the properties of the embryo or the endosperm (i.e. morphological or physiological) and

3) Combined dormancy.

## Pre-Treatment Methods for Overcoming Exogenous Dormancy

### Soaking in Cold Water

With a great number of species, soaking in cold water from one to several days is sufficient to secure germination. The improvement in germination caused by soaking in hot or cold water is caused by the softening of the seed coat and the ensuring of adequate water absorption by the living tissues. Cold soaking is used, for example, for the Himalayan pines and in Japan for pine and spruce seeds. When long soaking periods are used it is recommended that the water be changed at intervals. It is usually important to sow the seed immediately after soaking without drying, because drying generally seriously reduces the viability of the seed. An exception to this is *Acacia mearnsii* in southern Africa which is dried after hot water treatment and stored for three weeks. Also, in some countries teak seed is given alternate soaking and drying.

### Soaking in Hot or Boiling Water

The seeds of many leguminous species have extremely tough outer coats which can delay germination for months or years after sowing unless subjected to pre-treatment by immersion in boiling water. Examples are *Acacia decurrens*, *A. mearnsii* and *A. arabica*. The seed is immersed in two to three times its volume of boiling water where it is allowed to soak until the water is cold. The gummy mucilaginous exudations from the seed coat are then washed off by stirring in several lots of clean water.

Sometimes acorns, chestnuts and similar fleshy seeds give better germination if scalded, that is dipped for only 15 - 30 seconds in boiling water, which kills the insects and grubs often found on the seeds. If the scalding is prolonged above one minute, however, the seed may be killed.

### Acid Treatment

Soaking in solutions of acid is used in the case of seeds with very hard seed coats such as *Acacia nilotica* and *Albizzia lebbeck*. Concentrated sulphuric acid is the chemical most generally used; after soaking the seed must be immediately washed in clean water. Tests should be made to determine the optimum period for treatment for each species, and even for different provenances, since over-exposure can easily damage the seed.

Examples of the recommended times for soaking in acid of seeds of a few *Acacia* species are (Laurie, 1974):

| Species | Time (minutes) |
|---|---|
| *A. albida* | 20 |
| *A. nilotica* | 60 to 80 |
| *A. senegal* | 40 |

### Other Treatments

In special cases seeds are scarified, for example in revolving drums, to crack or pierce the outer seed coat. Sometimes the seed has to be cracked or cut open, or partially cut by hand (e.g. *Pterocarpus angolensis* and *P. pedatus*) to obtain good germination. Germination of *Pinus lambertiana* was improved by removing the seed coat and membrane. In some countries (e.g. India and Sudan), seeds of *Acacia* and *Prosopis* species are fed to goats and later collected from their droppings; the partial digestion in the gut is held to enhance germination, but the method has obvious difficulties in application and is now only used if acid treatment is not possible.

## Pre-Treatment Methods for Overcoming Endogenous Dormancy

### Stratification

Stratification means the storing of seeds in a moistened medium, for example peat or sand, so as to maintain viability and overcome dormancy. If seed is stored moist in near-freezing temperatures, the method is called cold stratification or pre-chilling, even if no medium is used. Stratification is commonly used for large, fleshy seeds, such as acorns, walnuts and teak. The seed is usually stored in a pit or trench in alternative layers with moist sand, peat, leaves or straw, and the heap is covered to keep rain off and protect from the depredations of rodents.

Moist cold stratification is commonly used to break dormancy or improve germination for a range of pine seeds (Schubert and Adams, 1971). In this method:

1) The seeds are thoroughly mixed with moistened sterile river sand or vermiculite;

2) The mixture is poured into trays or cans with bottom drainage holes and

3) The containers are placed in refrigerators at 0.5° to 2.0°C for the period to break dormancy.

The medium has to be kept moist through the stratification period. To minimize the formation of moulds the seed should be treated with a fungicide such as Captan before stratification. An alternative method is to soak the seed for one or two days and, after draining off the excess moisture, to seal the seed in polythene bags for storage at 0° to 2°C. The time required to break dormancy is variable, for example *Pseudotsuga menziesii* takes 40 to 150 days depending on the origin of the seed and *Pinus ponderosa* required some 30 days, so that trials and investigations are necessary to determine optimum periods for species in selected areas.

In Japan a form of stratification under snow is practised to quicken the germination of certain species (e.g. *Abies sachalinensis*, *A. homolepis*, *A. firma*). After a short wetting the seed is spread evenly on a prepared site and covered in clean river sand. The sand is then covered with straw upon which a pile of snow 1.5 to 2 m thick is packed. The snow is replenished from time to time until the spring thaw arrives and the seeds are ready for sowing.

Warm followed by cold stratification has been found effective for a considerable number of species (e.g. *Fraxinus excelsior*). The seeds are held at germination temperatures for one to several months, after which they are shifted to cold chambers or refrigerators and held at low temperatures for an additional one to several months.

### Treatment with Chemicals

Chemicals, such as hydrogen peroxide, have been found effective in breaking internal dormancy in most seeds (e.g. *Pseudotsuga*, *Abies* and southern U.S.A. pines). Gibberellic acid has been shown to enhance the germination capacity and even to stimulate meristematic growth rates, while a number of forest tree seeds respond to treatment with various organic compounds, including citric and tartaric acid. Other tested and effective chemical treatments have included potassium nitrate (1 - 4% for 24 hours) and red copper oxide or zinc oxide dusts.

## Pre-Treatment Methods for Overcoming Double Dormancy

To overcome double dormancy it is necessary to treat the seed so as to make the seed coat permeable and induce in the embryo the changes essential for germination. Sometimes cold stratification is sufficient, but more often hot water soaking, acid treatment or scarification followed by stratification is necessary. Warm followed by cold stratification has also given good results in many cases.

## SEED COATING AND PELLETING

Where seed-eating pests cause serious losses, the seed should be treated with insecticides and rodent and bird repellents before sowing. Chemicals such as arsenate and endrin are used against insects and rodents; arasan and anthraquinone are effective bird repellents and fungicides.

The development of seeding from the air has stimulated experiments in coating the seed with hygroscropic substances containing nutrients and toxic repellents. These artificial coatings add weight to some of the lighter seeds, thereby improving the scatter pattern in aerial seeding. A coating formulation consisting of endrin and arasan as the repellents, with a latex sticker to act as a bond, has been successfully used with Pinus palustris and P. taeda in southern U.S.A. The seedling yields in field studies comparing coated seed with untreated seed were 55 : 1 for P. palustris and 12 : 1 for P. taeda (Derr and Mann, 1971). Aluminium powder has been found useful as a lubricant for seed pellets. In East Africa Rhizoctol combi is used in pelleting P. patula seed as a protection against damping off.

## SITE PREPARATION

In most cases, direct sowing will not be successful unless the seed is in contact with mineral soil and preferably covered by a thin layer of protecting earth. Exposure of the mineral soil can be achieved by burning or by clearing and cultivating. Controlled burning is an important method of site preparation for eucalypts in Australia, especially in the wetter forest types and is also used extensively for aerial sowing of pines in southern U.S.A.

Land clearing and cultivation prior to sowing may be done on the whole area to be seeded or it may be restricted to strips or spots. On sloping land cultivating is generally done in bands (either continuous or interrupted) following the contour. Where soil erosion is a danger, it is usual to leave the native vegetation undisturbed in the bands between the cultivated strips.

In Tanzania a method called "tie-ridging" has been found effective, especially for Cassia siamea plantations. With this method the whole area is cultivated and ridges are built up at intervals by hoeing. Tie-ridging is generally used on gently sloping land where the basins are very effective in controlling surface runoff. Sowing the seed along the ridges has given very good results. Wherever possible the growing of a forest crop is combined with the raising of food crops.

The Indian "rab" method is also used in some dryer regions of the savanna type. The rab method consists of piling the slash cleared from the land in windrows or heaps and burning it when dry. The seed is sown directly on the ash after burning. The advantage of this method is that the burn partially sterilizes the soil, killing all weed growth and the surface population of termites and ants. The rows remain free of weeds for an appreciable period, and the ash provides a useful fertilizer for the seedlings. In Zambia a similar method, called "citemene" was used, but has been abandoned because of problems in carrying out a timely burn over large areas and in protecting the young crop from fire.

## TIMES FOR SOWING

In general, sowing should be done when soil conditions are sufficiently moist and warm to permit germination to start and to promote rapid early growth of the seedlings, that is to say in the spring or at the onset of rains. Moisture and rainfall are the main critical factors so actual sowing dates may vary from year to year. If sowing is prescribed on a preselected date regardless of soil moisture, there is a risk that initial rains will be sufficient to start germination but inadequate to sustain it. The soil should also be free of frost, but with some species higher soil temperatures are necessary for germination.

In areas subject to snowfall, especially in drier regions, there are sometimes advantages in sowing before the snow season. The seed is protected by the snow from birds and other seed-eating animals during the winter, and germinates immediately after snow-melt when conditions are favourable, which is an advantage when the onset of dry summer weather follows very soon after the thaw. In other cases, the seed is sown immediately after the snow has disappeared or sometimes on the surface of the snow as soon as the thaw conditions have set in.

In southern U.S.A. (Derr and Mann, 1971) sowing may be done during the spring or autumn, but best results are generally obtained from early spring sowing. In California, however, late autumn seeding offers a longer seeding period, avoids the need to stratify and results in earlier germination in the spring.

## DIRECT SOWING METHODS

### Broadcast Sowing

Broadcasting seed can be done by hand, by using a tractor mounted spinner of the type used in agriculture for spreading complete fertilizer or aerially by using aeroplanes or helicopters. Broadcast sowing is used for many species but requires much more seed per unit area sown (two or more times the quantity used in the other methods mentioned). It is used in circumstances where the seed supply is abundant and cheap and pre-supposes that only a relatively small percentage (30% or less) of the germinating seeds survive to establishment. If germination and survival conditions are good, then broadcasting may well result in too high a stocking of the land, requiring subsequent drastic reduction of the crop by hand or mechanical weeding methods. In such conditions line sowing, drilling or even spot sowing is less wasteful of seed. However, when seeding from the air is feasible, then over-stocking with subsequent thinning out of the seedlings is sometimes considered acceptable.

In New Zealand *Pinus radiata* plantations have been extensively established by aerial broadcasting, and in Canada direct sowing of *Pinus contorta*, *Pinus banksiana* and *Picea glauca*, partly from the air and partly by using tractor mounted seeders, is widely used, thanks to developments in seed-coating techniques. In Canada from 150 to 450 g/ha of seed is used in broadcast seeding depending on the species and the locality of sowing.

Broadcast seeding from the air has also been highly successful on a large scale for sowing *Pinus elliottii* and other fast growing pines in the southern states of U.S.A. It is the quickest and cheapest method, an aeroplane seeding 600 hectares per day and a helicopter up to 1 000 hectares. Broadcast seeding by machine is much slower, covering up to 35 hectares a day, while 8 hectares is about the maximum a man could seed a day.

The possibilities of reclaiming sand dune areas by aerial seeding followed by spraying the land with a coagulating chemical to fix the blowing sand is referred to in Chapter 4.

Wherever possible the seed should be covered for protection with a layer of soil of a depth equal to two or three times the diameter of the seed. Where the land has been previously clean cultivated this can be achieved by rolling the seeds in with a tractor drawn agricultural roller or by dragging a rounded log or baulk over the land with ropes or chains attached to each end and yoked to a tractor or to draft animals. Covering the seed has a marked effect on increasing the survival germination percentage.

## Sowing in Lines or Drills

Sowing in lines may be conveniently used either on clean cultivated sites or on land cultivated in lines or strips. The seed is sown by hand or can be drilled in with a modified agricultural seeding drill. Line seeding uses one-half to one-third the quantities of seed required for broadcasting. It is also the method best suited to sowing large seed. The distance apart of lines can be selected on the basis of growth rates or subsequent tending methods, and the spacing of seed in the line should be such as to ensure an adequate density of stocking.

Hand sowing in lines is still commonly used in many countries, particularly for small-scale afforestation schemes. It is the only possible method on planting sites prepared with tied-ridges and along contour trenches and gradoni on steep slopes. Sometimes a shallow furrow is drawn into which the seeds are dropped before closing the furrow in with a hoe or rake.

Very large seeds can be dibbled in holes made in the soil by a pointed stake. In Brazil the seeds of *Araucaria angustifolia* are dibbled in holes 10 to 20 cm deep at spacings of 1 to 3 m within the rows and 1 to 3 m between rows (Ntima, 1968). From one to three seeds are sown in each hole. A similar method is used with this species in Argentina, where lines are 1 m apart and within row spacing is 0.5 m. This close spacing requires 40 to 120 kg of seed per hectare. At year three the seedlings are thinned out to 2 500 plants/ha. Line seeding is also the general method used in Italy for *Pinus pinea* plantations; 50 - 120 kg of seeds per hectare are used, and the seeds are buried "a finger's depth" in the soil.

Where possible drilling with tractor drawn implements is often more timely and efficient than sowing by hand. A tractor and drill can seed 5 hectares a day while 25 men would be needed to do the same work in the same period. In Canada a specially designed drill seeder has recently come into use which is towed by a crawler tractor fitted with a V-shaped dozer blade. Use of this machine allows scarification of the soil and seeding to be carried out in one operation.

## Spot-Sowing

In this method, seed is sown in relatively small cultivated patches spaced at regular intervals corresponding to the desired crop spacing. Spot sowing is commonly used for such genera as *Swietenia* or *Gmelina* in the tropics with 2 or 3 seeds being sown in each spot.

In New South Wales, Australia, spot-sowing is the standard method of establishing plantations of *Eucalyptus pilularis* and *E. grandis*. The land is first cleared of vegetation which is later burned *in situ*. The seed is sown on the ground in small spots of 20 cm diameter at intervals of 2.80 x 2.80 m or 3 m x 3 m using a seed shaker or "pepper pot" container consisting of a screw-topped jar, or a plastic container with perforated lid through which the seed can be shaken but will not flow freely. Sowing rates for these species vary between 250 and 500 g per hectare. The same method is used for sowing *Eucalyptus* seed in Zambia and the Congo; however in these areas it has not succeeded as well as in New South Wales, where the two species are native. In general, *Eucalyptus* spp. in exotic sites are more successful if planted.

The Panama direct seeder is a lightweight hand tool used for spot sowing directly onto mineral soil. It has a trigger dispenser and an adjustable hole size which allows the operator to control the number of seeds released per spot. (Courtesy U.S. Forest Service)

The spot sowing method is commonly used for establishing conifer plantations in hilly regions, particularly in some Mediterranean countries, in the Himalayas and in Japan. In Japan the spots are about half a metre in diameter and are sown with about 50 seeds of *Pinus densiflora* which are covered by lightly raking over the spot.

Spots may take the form of rectangles which are often about 1.5 m wide and 2 - 4 m long, with the longer axis oriented along the contour. These rectangular spots are cleared of shrubby growth and cultivated with a mattock or hoe. In Italy, *Pinus pinaster* and *P. laricio* are normally sown in this way or on continuous cultivated strips using 6 - 15 kg of seeds per hectare. The method is also used extensively in Cyprus for re-seeding burned-over forests with *P. brutia*. Similar methods have been used with success for establishing *Cedrus deodara*, *Pinus griffithii* and *P. roxburghii* using 2.1 kg of *Cedrus* seed and 1.5 kg of pine seed per hectare. Almost double this quantity of seed is needed for sowing along continuous contour lines.

Another varient is "mound" or bed sowing, especially on moist sites or in poorly drained soils, where the soil is excavated from pits and deposited in a series of small, flat-topped mounds, on which the seed is sown or dibbled.

Spot sowing is sometimes used in taungya plantations, the spots being marked by a stake driven into the ground so that the cultivator can take precautions against injuring the seedlings during weeding or harvesting work.

## Replacement Seeding

Failures after seeding operations are filled by re-seeding the following year or by transplanting seedlings found growing in excessive numbers in other parts of the area. In the case of fast-growing species, it is advisable to fill the blank spots by planting nursery grown plants rather than to attempt re-seeding. An essential is to determine the reason for any failure, in an attempt to ensure that any causal factors will not similarly affect any re-seeding.

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# CHAPTER 3

# PLANTING AND TENDING

## PLANTING

The decision to afforest on a reasonably large scale should always be based on a series of trials or research to determine effective methods of establishment. Both direct seeding, primarily because of its possible cheapness, and planting with nursery stock should be considered, but planting is by far the most common method.

Planting allows for regular spacing which favours good utilization of the site and facilitates subsequent tending operations and plantation management. On difficult sites, particularly in dry regions, planting has proved by far the most effective method, indeed often the only method, of establishing plantations. It is also often the most successful method for fertile productive sites where competition from weed growth is fierce. When seed supplies are scarce or costly, nursery production and planting offer the best opportunity of using seed efficiently; while in circumstances where plants are reproduced vegetatively, such as hybrid poplars or species that produce little or no viable seed, there is no alternative to planting.

The main disadvantages of planting when compared with direct sowing are the cost and time required to produce nursery stock, the high costs and transport problems in moving stock to planting sites without deterioration in their condition and the increased requirements in number and skill of planting teams. Unskilled or careless planting often results in poor survival or in root deformation that adversely affects growth and stability.

The essential principles of planting are that:

1) The planting stock should be healthy and vigorous;

2) The selected trees should be suited to the planting site, and such sites should be prepared to a condition favourable for the tree crop, and

3) Planting should be carried out in an efficient and timely fashion and the seedlings should be given proper care and protection during and after the planting operation.

## Kinds of Planting Stock

The kind of planting stock used has a direct bearing on the planting method. The main types of planting stock are bare-rooted, ball-rooted, potted and tubed plants, stumps, cuttings and sets.

### Bare-Root Plants

Bare-root plants are despatched from the nursery after shaking the excess earth from the roots, leaving only a thin layer for protection. The plants are tied in bundles and protected from drying in transit by covering the roots with wet moss or leaves or by dipping them in clay slurries or specially prepared mixtures. The bundles are placed in paper or plastic sacks, cardboard cartons etc., for despatch. Plastic bags or paper sacks lined with plastic film have the advantage of being permeable to carbon dioxide but impermeable to water, thus minimizing the risk of drying. Bare-root plants are most frequently used in temperate regions or in other regions where the climate has a relatively high atmospheric humidity during the planting season. In temperate regions, seedlings are generally in a resting phase at the time of planting, and this facilitates bare-root planting. However, plants are liable to a loss of viability, even in humid climates, if the roots are exposed to sun or wind; they should, therefore, always be kept covered on delivery at the planting site until the time for planting out arrives. Whenever there is a possibility of a delay of more than a few hours between delivery and planting, the bundles should be "heeled in" - that is to say, placed in specially dug trenches and the roots covered in moist sand, peat or light earth. Plants that have been carefully heeled in and kept watered can survive several days, even weeks, without damage.

"Striplings" are large nursery plants with a 1 to 2 m shoot which is stripped of leaves prior to despatch for planting. Stripping off the leaves reduces transpiration losses. Such plants are used mainly in the tropics where browsing is a special hazard.

"Wildings" are natural forest seedlings or root suckers which are sometimes used for planting when nursery stock is either too small or in short supply. They are most often used in enrichment planting operations.

### Ball-Rooted, Potted or Tubed Plants

In ball planting, the plants are despatched from the nursery with their roots enveloped in nursery soil, which protects them from drying and reduces physical damage to the roots as a consequence of lifting from nursery or transplant beds. A method developed in East Africa, for example, is to carve up the nursery bed into sections and to place the sections into shallow-sided boxes, or to grow the seedlings directly in the boxes. At the planting site, individual seedlings with small blocks of soil are cut from the box for planting.

The main problem with ball planting is to prevent the soil from being shaken loose from the roots during transit from the nursery to the planting site. To overcome this, different techniques have been tried, such as enclosing the bare roots of nursery stock in balls or blocks of specially mixed and compressed earth (usually consisting of clay, sandy loam and peat or humus in equal parts), or in earth-filled containers. Stock thus treated are termed "balled-plants". In a similar method developed in Brazil, and formerly used on a large-scale, the potting soil is compressed by a machine to form a soil block, called a torrao paulista, into which seed is sown.

On a much wider scale, the problems of root exposure have been largely overcome by the use of seedlings raised in some form of container. Plantation systems using container-grown stock are now common in most parts of the world, and are used almost exclusively in areas with a marked or long dry season. Container plants have a considerable capacity to withstand limited dry periods following planting; their use therefore can prolong the planting season, particularly in temperate zones, and to a much lesser degree in harsh environments.

Containers can be either "pots", which have a closed bottom, preferably with drainage holes, or "tubes", which have no bottom but require a soil medium that is sufficiently adhesive not to fall out when handled.

The use of containers made of polythene has become widespread; but prior to their development, various other materials such as metal, bamboo, wood veneer, banana or palm leaves, cardboard and waterproof paper were widely used in different parts of the world. Although still used in some areas, most of these are either more expensive or less convenient than polythene, which has the advantages of being cheap, light and easy to handle and has generally proved effective over a wide range of conditions. The polythene used for containers is usually 150 to 250 gauge (0.0375 to 0.0625 mm thickness) and is generally black or transparent, the black being more durable.

The size of container varies with species, age and size of stock preferred for planting as well as harshness of the site. In Nigeria, for example, in areas with less than 800 mm of rain, and a dry season of at least six months, pots 25 cm long by 25 cm circumference are used, while in areas with over 800 mm rainfall, smaller pots 15 cm by 25 cm are used, and experiments using pots 15 cm x 15 cm are being actively continued. In Zambia tubes 15 cm by 25 cm were standard, but "minipots" 15 cm by 15 cm have been developed and are extensively used. The size of a container has an obvious effect on its weight when filled with soil. For example, in Nigeria the different sizes of pot filled with soil weigh approximately: large, 1.9 kg; medium, 1.1 kg and small, .4 kg. The work input and cost of transporting container seedlings increases with the size of container, which underlines the impetus for research into the use of minipots and "tubelings". An objective in container planting should be to use the smallest container compatible with successful establishment and subsequent growth and development.

The use of containers has occasionally caused root malformation of seedlings, with an adverse effect on their subsequent growth and development, and one disadvantage of small pots is that they may increase the chance of such malformation (Ball, 1976). When plants are kept too long in containers, the restriction of lateral root growth may cause distortion, coiling and spiralling which may later lead to basal stem snap, reduced wind-firmness and stunted growth, and in extreme cases it may result in mutual strangulation of roots and the death of the tree. These symptoms, however, may not always appear, or may not become apparent until some years after planting. In Nigeria, for example, in trials of removal, partial removal or retention of polythene bags at the time of planting, there were indications of increased mortality in four-year-old pines when bags were not removed, but in eucalypts up to seven years old removal made little difference (FAO, 1976). To reduce the risk of root coiling, it is important to time nursery operations so that plants do not become too large for their containers before out-planting; and to mitigate the damage from coiling it is advisable to completely remove the container at the time of planting. In addition, Ben Salem (1971), Stone (1971) and Donald (1968) recommend making two or three vertical incisions about 1 cm deep down the length of the soil cylinder with a sharp instrument to cut any coiling roots.

In recent years new types of container have been developed in North America which are designed to minimize root coiling (Tinus <u>et al</u>., 1974). The inner walls of these containers have vertical ribs which channel the roots to a central bottom hole. By supporting the containers clear of the ground, emerging roots are killed back by "air pruning", thus encouraging growth of numerous laterals into a tapered form. The plant and growing medium (together called a "plug") are removed from the container at the time of planting and are inserted into the soil with the aid of a specially made dibble.

## Stumps, Cuttings and Sets

"Stump" is a term applied to large nursery stock of certain broadleaved species which has been subjected to drastic pruning of both the roots and the shoot. The top is generally cut back to about 2 cm and the root to about 22 cm (Parry, 1956). Stump planting is especially suitable for taproot dominated species and is frequently used when establishing teak, gmelina and a number of other important tropical genera (e.g. *Afzelia*, *Cassia*, *Chlorophora*, *Entandrophragma*, *Khaya*, *Lovoa*, *Pterocarpus*, *Terminalia*, *Triplochiton*, *Bischofia*, *Dalbergia* and many Leguminosae. Stumped plants of *Acacia cyanophylla* are also used in arid zone drift sand stabilization plantations. During transit stumps are normally covered with wet sacks or layers of large leaves.

Cuttings and sets are also commonly used as planting stock in reforestation programmes. A cutting is a short length cut from a young living stem or branch for propagating, i.e. producing a whole new plant when planted in the field. A rooted cutting is one that has been rooted in the nursery prior to field planting. Sets are long, relatively thin, stem cuttings or whole branches, such as those sometimes used for propagating willows.

Trees easily and commonly propagated by cuttings include poplars, willows and gmelina. For some harder to root species, rooted cuttings are sometimes used in reforestation to supplement scarce seed supplies and as a means of tree improvement (Brix and van den Driessche, 1977). Rooted cuttings of *Cryptomeria japonica*, for example, are common in Japan, and *Picea abies* rooted cuttings are used in West Germany and Finland. Extensive research on rooted cuttings is being conducted in New Zealand and Australia for *Pinus radiata*, in the United States for *Pseudotsuga menziesii*, in Nigeria for *Triplochiton* and in the Congo for *Eucalyptus* spp.

## Size and Quality of Planting Stock

There is a considerable range in what is considered the optimum size of seedling for planting. The optimum size varies depending on: 1) whether the seedlings are bare-root or container-grown, 2) the species and 3) the characteristics of the planting site.

It is generally agreed that plants with a well proportioned root/shoot ratio represent good planting stock, but except under detailed specified conditions it is difficult to define an optimum root/shoot ratio. A generalized ratio based on length might vary between 0.4 and 1.0, although a root/shoot weight ratio would give a more accurate measure of balance. Stem diameter and height are other criteria for grading planting stock that might allow the setting of minimum acceptable limits. In the United Kingdom for example, seedlings are graded by height and diameter, with bare-root conifers generally varying from 15 to 22 cm minimum height and from 2.5 to 4.0 mm minimum stem diameter (Aldhous, 1972). Such plants are usually from one to four years old and may have spent one or two years in transplant beds. In the tropics plants are ready for planting at between 3 and 12 months. Experience and research indicate that medium-size stock, for example conifers between 15 and 40 cm, with a woody root collar often have a better survival rate than smaller plants.

The morphological grading of planting stock must depend to a large extent on local research and experience and the setting of local standards. Studies in the United States have cast some doubt on the adequacy of such morphological grading as a survival index, and research is currently being directed towards the determination of physiological criteria and in particular the capacity for rapid root development following planting (Kozlowski, 1973).

In the case of tubed or potted stock, the maximum size for planting out is largely determined by the size of the container. The larger the container the larger the plant that can be grown in it, but the period is limited to that period free of harmful root restriction. For eucalypts in the Sudan and Nigeria, plants are usually 20 to 30 cm high from root collar to tip. In Zambia there is a trend to smaller eucalypt plants 10 to 15 cm high, and for pines 15 to 20 cm is specified for standard tubes and 10 to 15 cm for minipots. Very small plants may be subject to frost heaving in temperate regions, whereas excessively tall plants are liable to be blown over or loosened in the ground, and root development may be restricted or inadequate to cope with the high transpiration demand of a large top.

Planting stock should as far as possible have been hardened-off in the nursery prior to planting, but this is not always possible with fast-growing species such as eucalypts.

A further factor affecting grade of stock is the state of the planting site. It is possible, for example, to successfully plant smaller seedlings on clean cultivated sites than in weed-covered uncultivated land. A high standard subsequent weeding regime can also compensate for smaller stock at planting.

## Timing of Planting

In general the best time to plant is when the soil is moist and free from frost, when atmospheric conditions are humid and evaporation rates minimal and if possible when plant shoots are in a dormant state. Dry, sunny and windy days should be avoided. In many of the cooler temperate regions the best planting time is in spring when ground temperatures are above 4 - 5°C. In the Australian temperate regions planting is mainly during the winter; in California it is in the late autumn, winter and early spring. Spring planting generally limits the period suitable for planting to about one month, except for container plants for which the planting season may be slightly extended. Delays in planting which prevent taking advantage of optimum periods reduce the degree of success, and long delays may result in complete failure.

In some moist tropical or equable climates, planting may be feasible over much of the year, but in other regions where there are pronounced wet and dry seasons, planting operations should coincide with the onset of the period of regular and continuous rains and should begin as soon as the soil has become sufficiently moist. In Zambia, for example, planting is started when the soil is moist to a depth of 30 cm. In East Africa a formula has been evolved to determine the soil moisture buildup based on daily rainfall and temperature readings (Griffith, 1957). Briefly, this method ascertains the daily loss of moisture from the soil by evaporation and a measure of the daily gain from rainfall. A running gain and loss account is kept, and when a certain amount of soil moisture has accumulated, planting is commenced. The amount has to be calculated for each planting locality and depends on type of soil, altitude, local probability of rainfall and the tree species being planted. Such a procedure brings greater certainty into the decision of when to start planting, but still requires judgement based on a knowledge of local rainfall patterns.

In many savanna areas the optimum period for planting is only one month or less. To achieve extensive planting programmes in such a limited period requires considerable planning preparation and accurate calculation of probable planting dates. In Nigeria, for example, Kowal (1975) estimated planting dates for a number of savanna stations with Penman's formula based on reliable synoptic stations. By programming nursery and land preparation to such planning dates, it should be possible to slightly advance or delay planting to take advantage of actual favourable climatic conditions occurring either side of the estimated dates.

The use of container stock can extend the planting season, since the plants are more tolerant of climatic variations, particularly dry spells, than bare-root stock. Even in dryer regions planting can be extended outside the normal planting season, provided the plants are watered or irrigated until they are established.

## Plant Spacing

As the spacing between plants varies with a number of often conflicting requirements, the selected spacing may be a compromise between silvicultural and managerial objectives. Close spacing, for example, may be desirable to achieve early canopy closure with consequent suppression of weeds and reduction in the weeding period, but if soil moisture is a limiting factor at certain times of the year a wider spacing may be required if stagnation of the plantation due to a moisture deficit is to be avoided. The early taking-over of the site by the plantation crop is not only of consequence in suppressing weed competition but also reduces any fire hazard at a stage when the crop is particularly vulnerable. However, while a close spacing will produce early canopy closure, it may also create a need for early and unsaleable thinnings.

Some of the factors influencing the choice of planting distances are:

1) The growth rate of the species planted. Slower growing species tend to be planted at closer spacing than faster growing species, and for this reason spacings in the tropics tend to be greater than in temperate regions.

2) The growth form of the species planted. Some species have a very branchy form and need to be planted closely to promote the formation of a well-defined leading stem. Other species, including many of those from the tropics, are self-pruning and can therefore be planted more widely apart.

3) The hazard posed by competing weed growth. Despite the fact that close spacing reduces the time to canopy closure, it may well increase the difficulties and costs of weeding. Mechanized weeding requires a spacing between tree rows sufficiently wide to allow for the passage of a tractor and implement. A distance of 2.8 m between rows is considered a minimum spacing where weeding is mechanized.

4) The availability of soil nutrients and soil moisture. In shallow soils, or on sites with frequent rock outcrops, the spacing will tend to be wider allowing more room for root development or it may be irregular to conform with the distribution of soil pockets among the rocks. In arid regions, soil moisture is often a limiting factor and the general practice is to use fairly wide spacings, especially where inter-row cultivation is practised to promote rain water retention.

5) The influence of drainage or irrigation works. The layout of drains in wet soils or of the water channels in irrigated plantations can also influence the spacing of planting lines. For example, in plantations on peat lands, where the trees are planted along ridges turned up by drain ploughs, the spacing and the drainage pattern have to be coordinated.

6) Future management. If it is policy to reduce the number of early and often unsaleable thinnings wider spacing is recommended, as in the case of some plantations of fast growing tropical conifers where crown closure is delayed in the interests of promoting diameter growth. The costs of high pruning the final crop stems is an additional debit. On the other hand, closer spacing can be adopted if the production of fuelwood, small diameter poles, or pulpwood is the object of management. In cut-over tropical high forest, wide spacing of planting lines coinciding more or less with final crop espacement has been adopted leaving inter-bands of natural regrowth, and in taungya plantations the tree crop spacing has to be sufficiently wide to allow the cultivator to carry out his cropping over a reasonable period.

7) Financial aspects. Costs for plants and labour tend to increase with decreasing planting distances, but on the other hand, costs of weeding tend to increase with wider spacing.

## Organization of Planting Operations

### General Layout

The general layout of the entire plantation area with the planned subdivisions, roads, rides and drains will have been delineated on the plantation maps, as noted in Chapter 6 on plantation planning.

The area programmed for planting in any particular year will normally be made ready for planting prior to the estimated planting date. Compartments will be surveyed and delineated by roads, rides, tracks or firebreaks. All corner and intersection points should be marked by plainly visible, more or less permanent beacons. An essential feature is that there should be sufficient all weather roads in the planting area to allow the transport of plants and access for labour to carry out planting and subsequent operations. Where mechanized operations, such as weeding, are planned, sufficient space should be left for tractor turning, not necessarily at the end of each compartment but at that boundary which might serve as the end of weeding runs.

### Marking or Pegging for Planting

With the possible exception of plantations on hilly ground where soil conservation works following the contour are necessary, planting should wherever possible be in straight lines. This is mainly to facilitate weeding operations after planting, and is equally important whether hand, mechanical or chemical weeding is employed. Plants which are out of line (and often obscured in weed growth) are more liable to be cut or injured during weeding. The maintenance of straight lines is not of the same consequence where there is no subsequent weeding.

Except up or down hill, straight line planting is not of course possible on sloping ground under conditions where contour soil or water conservation works form part of the site preparation work. On such sites planting lines normally follow the direction of the contour banks, steps or ridges.

There are many variations in marking out or pegging planting lines, but for straight line planting squaring is the most common. Commencing at the corner of a compartment and using a compass or optic square, the corners of an exact square are laid out and pegged. The sides of the square will be the length of the planting chain and will be an exact multiple of the plant spacing. Planting chains are tagged at the plant spacing and are generally from 30 to 80 m long. From the outer pegs of the original square two base lines are laid out at right angles, placing pegs in the ground at the end of each planting chain length. Returning to the starting point, and using the chain, the corner of other squares are sighted in from the original pegs until the entire area is squared. Adjacent compartments should have their pegging aligned to that of the first to facilitate subsequent operations. It is important to carry out periodic checks to ensure that the distance between pegs is being accurately maintained. Chains should be checked for stretching during the operation. At any irregular compartment edges, with sections less than the participating chain length, a peg should be inserted at that last planting tag which comes within the planting area. Where mechanized weeding is envisaged, the base lines should leave a margin of 2 m or more between the edge of the road and the planting line to allow for weeding. Such squaring is usually adequate for subsequent pitting or planting operations, but in some areas the tagged planting chain is also used to peg the plant spacing along the two opposite sides of each square.

Another method of marking is to use a light tractor fitted with a boom carrying tines at set intervals which mark the planting lines by scratching parallel furrows in the soil. When repeated at right angles the intersections mark the planting spots. This method depends on the tractor driver's ability to steer a straight course on his sighting beacon, and is only feasible on relatively level surfaces free of obstructions. Similarly, where subsoiling is carried out during preparation work, the planting lines correspond with or are close to the furrows of the subsoiler tines.

In cases where cross cultivation or weeding by tractor and implement is prescribed for post-planting tending work, it is important to ensure that the planting pegs are in straight lines in two directions.

Where pit planting methods are planned, pits may be dug soon after pegging out, or may be done at planting time. Where notching methods are used, it is common for the planters to pace out planting distances as they plant, a skilled planter being able to maintain the planting line by eye. Mistakes, however, can be made if the planter is careless or tired, so that where inter-row tending by mechanical means is prescribed it is always advisable to take the trouble to peg or chain planting lines.

## Organization of Planting Work

The sequence of all operations preceding the actual planting must be so timed that planting can begin immediately site conditions become suitable. If, as has been noted, the planting season is relatively short, it becomes important to ensure that adequate supplies of planting stock are distributed at depots easily accessible to the planting area.

The success or failure of a plantation depends to a great extent on the skill of the planters. If skilled men are not available for this work it will be advisable to provide training before planting begins.

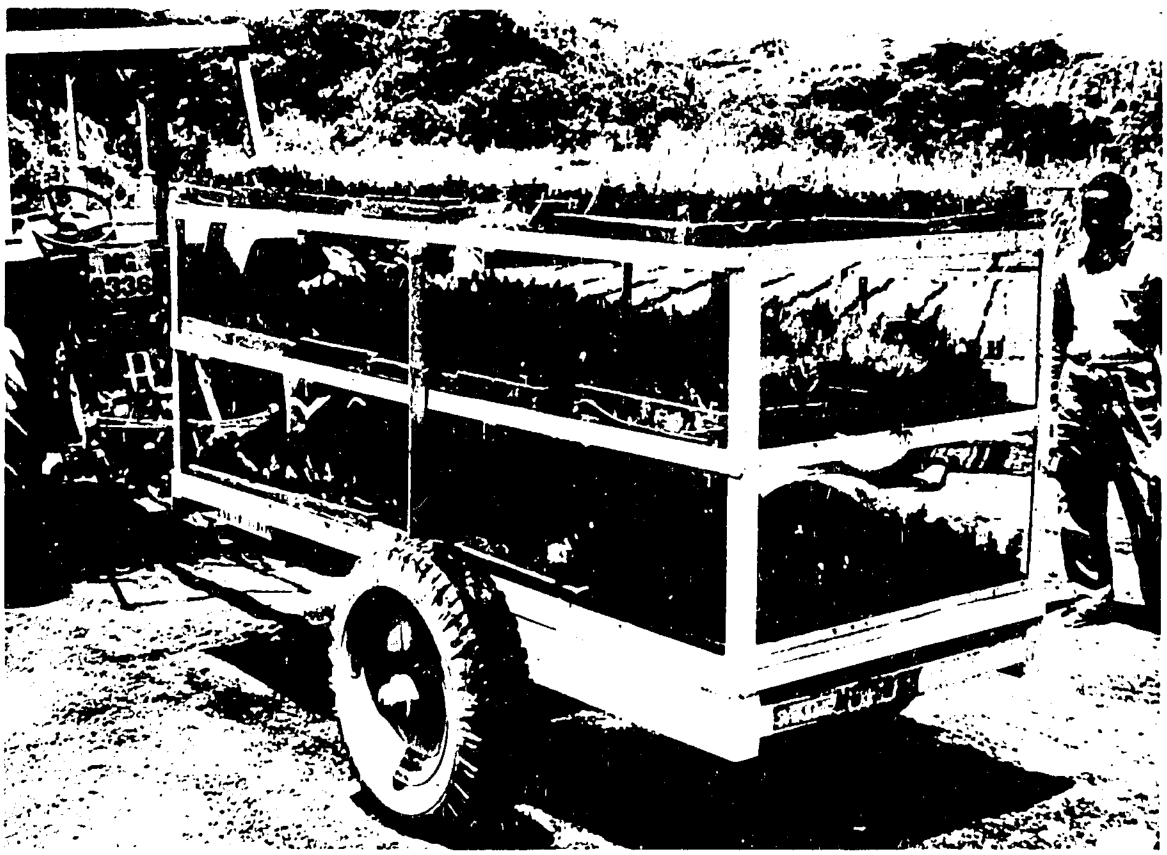
The forester or supervisor in charge should ensure deliveries of plants from the nurseries in such quantities as to keep the planting gangs fully at work. This requires a knowledge of 1) the average labour planting rate, 2) the planting method used, 3) the size and type of plants (bare-root or container), 4) the terrain and soil type and 5) the skill and experience of the planters.

Since planting stock is liable to deterioration from exposure, the forester should gauge deliveries so that stock is planted during the same day as delivery, but usually some surplus stock has to be carried to provide for emergencies. Stock not required for immediate planting should be protected against exposure by "heeling in" of bare-root plants or by placing container and ball-rooted plants in depots where the plants can be shaded and watered. The roots of all plants should be kept moist. The feasibility of treating the shoots or the roots of planting stock with chemical anti-transpirants is under investigation and trial in many countries.

In exceptional cases, for example, where plants need to be delivered to the planting site before snows block road communications, the establishment of temporary storage nurseries should be considered.

The means of distribution of planting stock from the main off-loading or delivery point to the actual planting areas depends largely on the terrain, the transport available and the type of plants. Bundles of bare-rooted plants can be carried to the site by men, by pack transport or by four-wheel-drive vehicles, depending on the terrain. The plants are subsequently collected by planters who refill their bags or containers from local depots spaced out at short intervals over each day's planting area.

Container plants are normally despatched from the nursery packed in wooden trays or boxes of standard dimensions conveniently handled and carried by one worker. The number of plants per container may also be conveniently matched to the number of plants required between squaring pegs. The trays are loaded on tractor trailers for transport to the planting areas or, in very steep terrain where animal transport is used, on specially designed saddles. The trays are off-loaded at intervals along the planting lines ahead of the planting gangs. The carrying capacity of lorries and trailers is greatly increased if the lorries and trailers are fitted with shelving allowing trays to be stacked in tiers.



Multi-level tractor trailers of various sizes can be constructed for transporting tree seedlings from the nursery to the planting sites. The trailer of limited capacity shown here is suitable for planting small areas near the nursery and for replacement planting; for more extensive areas, greater transport efficiency can be attained by using larger trailers. (Courtesy D.A. Harcharik)

## Planting Methods

Proper attention to detail in planting is often of greater importance than the method itself. It has been indicated (Wakely, 1954) that depth of planting and proper closure of the planting hole are the more critical factors affecting survival.

### Hand Planting

The two main manual techniques are notching and pit planting. Notching is used only with bare-root plants. In its simplest form it consists of cutting a slit in the ground with a spade or mattock, opening the slit wide enough to insert the roots of the plant, and finally closing the slit by pressing with the foot or heel. Variations consist of the T notch and the + notch. Both require a double slit, which takes longer unless a special tool is used, but the plant roots can be better spread than in the simple notch which tends to set the roots in one plane. When planting on turf or peat ridges and mounds, the slit should penetrate the ridge only as far as the original surface of the ground, as experience indicated that survival rates are less satisfactory if the roots are set deeper than this.

Dibbling is a variant of notching in which a planting bar or dibbling stick is driven into the ground creating a slit into which the plant is inserted and firmed by driving the bar into the ground beside the plant and levering the soil lightly against the plant. Dibbling is used for planting bare-root stock, unrooted cuttings, sets and sometimes for stump plants.

Ball-rooted or container stock can only be planted in pits. Pits are very often of much greater dimensions than the ball or container. It has been suggested that larger pits may have beneficial results in uncultivated sites as this provides a greater zone for early root penetration. In general, however, a pit that will readily accommodate the seedling roots is adequate.

For container-raised seedlings, manual digging of the planting hole is the standard technique. A hoe, such as that shown here in use near Ain Beida, Algeria, is a suitable tool. (FAO photo)

Pits are usually dug with types of spade or a broad-bladed mattock, the top soil being kept separate from the subsoil, so that it can be filled in first at the time of planting. In some countries pits are excavated some months before planting to allow the spoil as well as the exposed sides of the pit to be moistened by rainfall. On sites that have been already ploughed this is not so necessary, and the digging of pits is then carried out just ahead of or at the time of planting.

Pits can also be dug by power-driven borers or augers. These are either hand-carried or tractor-mounted; the latter are driven from the power takeoff. Tractor-mounted augers can dig about 10 times faster than a man, but their operation is restricted to flat areas, and they are costly to operate. Tractor-mounted borers are, however, very suitable for planting poplars and similar tall stock, for which deep holes (0.5 m or more) are needed. One disadvantage of mechanized borers is the danger of glazing or compacting the sides of the planting pits.

All types of planting stock can be planted in pits. When bare-root stock is used the plant is held in the pit so that it will be set at about the same depth or not more than 3 cm deeper than it grew in the nursery, and the roots are spread out freely. Using the other hand, half of the pit is filled and packed with moist soil. The remainder of the pit is then filled, packed and consolidated. At the end of the operation the soil in the pit should be level or slightly higher than the surface of the ground to allow for the earth sinking after rain or watering. For this reason it is usual to bury the root collar a few centimetres, so that after consolidation it remains at or near the surface of the ground. If the root collar is exposed, survival may be jeopardized. In dry regions it is usual not to fill the pit to ground level so that a depression is left to collect rain water or dew, but in heavy soils with low percolation rates, such depressions can retain water for several weeks, causing localized waterlogging resulting in the death of the plant.

Deep-planting, whereby the plant is almost completely buried, leaving only the tip of the shoot exposed, is practised in arid regions on driftsand or loose textured soils where the top layers of the soil are liable to dry out completely during the summer. Such soils frequently have a moist layer below the capillary lift zone (the layer to which ground water is lifted by capillary forces), into which the roots must be planted.

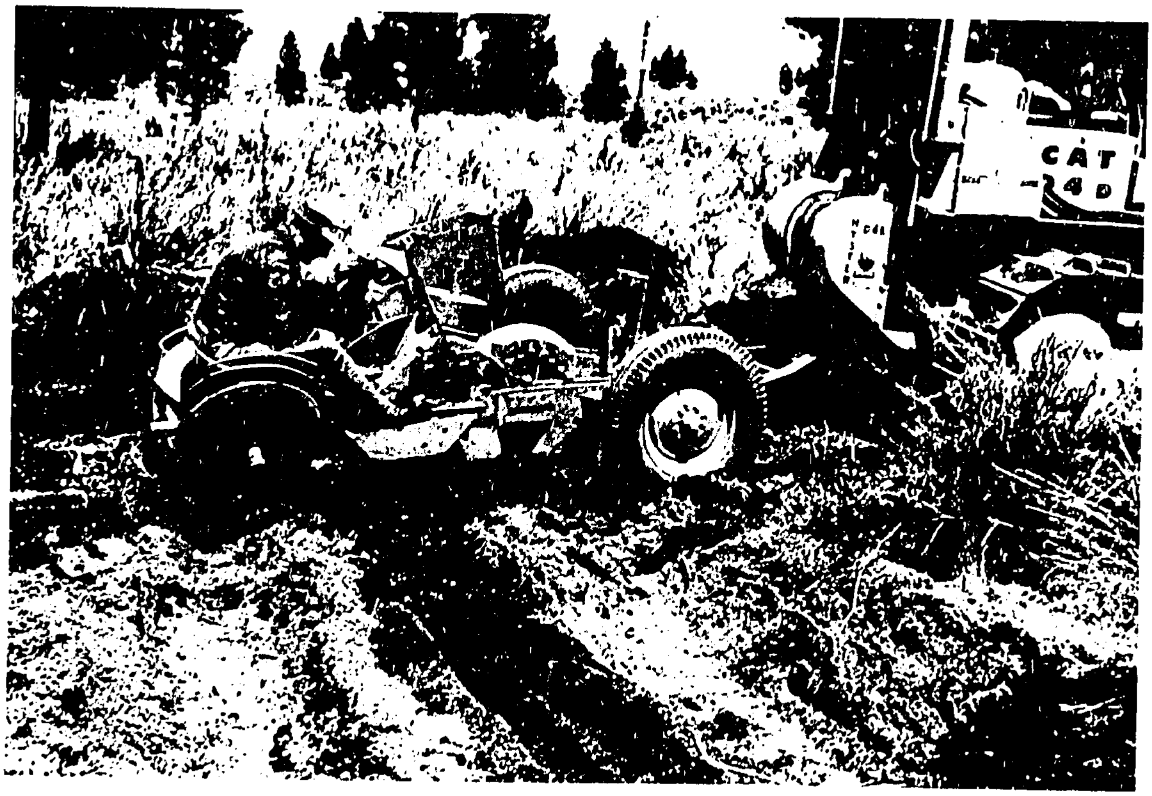
When planting container stock, a pit just slightly larger than the container is made with a trowel, dibbler or mattock. It is usually necessary to remove the plant from the container, or to slit or cut it before planting. For full removal of a polythene pot, a knife or razor is used to slit the pot, the bottom is torn off and the remaining tube is slipped off as the seedling is placed in the pit. Partial removal is similar except that some 7 cm of the upper tube is left around the soil cylinder. This forms a collar, of which approximately 3 cm are left above the ground after planting. This practice is common in areas where termites are a problem, such as in African savannas. The object of leaving the collar is to prevent field soil covering the insecticide-treated pot soil during weeding. Such untreated field soil can serve as a bridge for termites to attack susceptible species. Once the seedling is in the pit, the excavated soil is used to fill any gaps or holes and the plant is thoroughly firmed in by foot pressure.

The soil round all newly planted stock should be firmed by trampling to avoid large air spaces from forming in the soil and to bring the earth into intimate contact with the roots. Firming also minimizes damage caused by wind which can shake the plant and disturb the roots in the period between planting and consolidation of the soil. Very tall planting stock is much more liable to wind disturbances, and where wind is a problem it may be necessary to drive wooden stakes firmly into the ground beside the plant and to tie the stem to the stakes. Staking newly planted poplars, which are often 2 to 3 m in height, is common practice.

Mechanized Planting

Planting machines are at present used mainly with bare-root stock. If correctly adjusted and used they generally give good survival, minimize root distortion and cover the ground quickly (e.g. up to 12 000 plants and more per machine daily), but they can only be economically used over large areas and are limited by topography and vegetation. By handling mainly bare-root stock, mechanized planting is mainly confined to temperate climates, but research and development is being carried out to develop planting machines for small container plants and other machines for poplar sets or cuttings.

Planting machines are either mounted on or towed by a tractor. Towed planters are the most widely used, but heavier mounted planters tend to be more effective on difficult sites and slopes. The basic machine operations are: 1) the making of a vertical cut in the ground, 2) opening up the cut to receive the seedling and 3) closing the cut and firming the soil around the plant. These basic operations may be supplemented by devices for removing vegetation, by water sprays or fertilizing systems or by a timer for more accurate plant spacing. The vertical cut can be made by a knife edge or a plough share but the most common tool is a straight or curved coulter disc, which has the advantage of reducing the pulling power required, of riding over obstructions and of cutting most soils easily. The opening device or "plant shoe" consists of a slotted piece of steel plate, with the front edge pointed and designed to lead into the cut and the back end open to allow the seedling to pass through. An operator in a seat or saddle situated behind the coulter disc feeds seedlings into the planting shoe at the required spacing. The final operation of closing the slot is achieved by two inclined rotating wheels, normally fitted with pneumatic tyres. Supplies of planting stock are carried in cradles on the machine within easy reach of the operator, and precautions are taken to prevent drying out of the seedlings.




Most planting machines, such as this one in operation in the U.S.A., are designed to handle bare-root seedlings. Development of mechanical planters suitable for container stock is now underway. (Courtesy K.P. Karamchandani)

High productivity rates can be attained by mechanical planting on areas of level terrain and few obstructions, such as these grasslands in Venezuela which are being converted to Pinus caribaea. (Courtesy B.J. Zobel).

Replacement Planting

Replacement planting, "in-filling" or "beating-up" are the terms used for replacing dead plants in a recently created plantation. The aim in all planting should be to have no replacement to do, but inevitably there are some failures due to such factors as poor planting, drought, frost or breakage. When deaths do occur, the plantation has to be assessed to determine whether the remaining trees are sufficient to establish a satisfactory crop. The time of sampling for replacement planting generally is related to growth rates and for fast growing species would be within weeks or a few months of planting, whereas with slower growing trees six months to a year and sometimes more after planting would be adequate.

What constitutes a satisfactory survival varies in different regions. In California, for example, for pine timber plantations planted at 3 m x 3 m a 46% survival at five years constitutes an acceptable stand. This is, however, a minimum standard and higher stocking survival is desirable (Schubert and Adams, 1971). In Nigerian savanna, a survival of 90% is desirable for eucalypts and pines planted at 3 m x 3 m, but when this falls below 80% an assessment is needed to determine whether replacement or total replanting is required. With high mortality the object of taking over the site may not be achieved, and a heavy influx of weeds can have a further deleterious effect on remaining trees and may create an unacceptable fire hazard. In Britain it is rarely considered worth beating-up a plantation if survival is 80% or better.

The distribution of casualties can also affect the need for replacement planting. For example, where failures are evenly distributed the average survival figures may be acceptable, but this may not be the case where deaths occur in groups or patches. To be effective, replacement planting must be carried out as soon as reasonably possible after planting, and rarely more than a year later, even with slow growing trees. Consequently it is important to carry out this operation with considerable care and with high quality seedlings at least as good as the original stock.

Serious failures, although sometimes attributable to unusual climatic conditions, are often due to errors in judgement or technique during the establishment process, for example, selecting the wrong site or species, inadequate site preparation, use of poor planting stock, careless handling, excessive exposure during transport, poor planting, pest or disease depredations or neglect of maintenance. Any serious failure requires careful investigation to determine the possible causes, so that remedial action can be taken in the future and before any replacement planting.

## Fertilizers and Mycorrhizae

### Soil Nutrient Status

Trees, as other plants, require from the soil an adequate supply of all thirteen essential elements for healthy vigorous growth. These elements are the macro-nutrients: nitrogen, phosphorus, potassium, magnesium, calcium and sulphur; and the micro-nutrients or trace elements: boron, copper, iron, zinc, manganese, molybdenum and chlorine. Unthrifty growth or even failure may indicate deficiencies of one or more of these nutrients, but poor growth may be due to other causes including:

1) Excess or deficient soil moisture,

2) Inadequate soil aeration,

3) Pathological condition (due to attack by insects, fungi, bacteria, viruses or nematodes) or

4) Soil conditions which inactivate the soil flora or fauna.

If soil nutrient deficiency is suspected as causing poor growth, the soil should be analyzed to discover which elements appear to be in deficit. Foliar analysis is another diagnostic technique which is being more frequently used. Local field tests should confirm the composition and quantity of fertilizer and the methods and times of application required to remedy the deficiency and give healthy growth.

The elements most commonly in short availability are phosphorus and nitrogen, and in experiments in which these elements were added increases of growth were most often obtained. However, nitrogen fertilizers in the absence of adequate phosphorus, either in the soil or in the fertilizer, have occasionally been deleterious and, even with sufficient phosphorus present, they do not always give positive responses unless there has been adequate rainfall and generally moist conditions prevail. Potassium rarely seems to give positive responses. In dry zones the application of fertilizers sometimes causes increased mortality in newly-planted areas, possibly due to high concentrations of the fertilizer salts in the soil solution if adequate rainfall does not follow. The worst damage is to be expected after light rain followed by a dry spell, and where rains at planting time are unreliable it may be advisable to defer fertilizer application until the rains have become established and there is no danger of the soil drying out (Laurie, 1974).

## Fertilizer Application

The main reasons for applying fertilizers are:

1) To allow the planting and growth of selected trees on sites where adequate tree growth is not possible due to general lack of fertility or to specific nutrient deficiencies and

2) To accelerate the growth rate of trees after planting so as to increase the chances of survival and to shorten the establishment phase.

Advances in the science and technology of forest fertilization have been fairly rapid over the past twenty years. The identification of phosphorus and nitrogen deficiency over extensive areas of plantation land have been promptly and effectively dealt with by the application of fertilizer technology adapted from agriculture (Bengston, 1973). Types of phosphorus and nitrogen fertilizers suited to particular forestry situations have been and are being developed.

The timing of fertilizer application is important. For some species and soils, addition of fertilizers at the time of, or soon after, planting may be beneficial; in other cases, fertilizers are applied years after planting. Numerous fertilizer experiments have been carried out, often with conflicting results. This is perhaps to be expected when the great variety of soils and of species is considered, and it is difficult to formulate generalized recommendations either for species or recommendations.

Fertilizer application is often by hand, but an extensive range of equipment has also been evolved, particularly for large-scale application. The types of equipment include:

1) Tractor mounted spreaders using air blowers or mechanical spreaders to broadcast fertilizers and lime,

2) Tractor mounted applicators which can meter and selectively apply fertilizers simultaneously with either site preparation or planting operations and

3) Aerial application by fixed-wing aircraft or helicopter.

Aerial application is excellent for large areas. The technique was advanced rapidly by the development of special disposal reservoirs or canisters which can be quickly fitted and removed. Since 1974, however, the steeply rising costs of fertilizers have encouraged new research and development of equipment and techniques which aim to economize on the amounts of fertilizer used by effecting more precise placement.

## Tree Response to Fertilizers

Fertilizer application to remedy deficiency conditions can often produce remarkable results. In many savanna areas, for example, eucalypts, in particular *Eucalyptus grandis*, are found to be very sensitive to low fertility, especially to boron deficiency. The symptoms of boron deficiency are leaf deformation, serious die-back during the dry season and frequently death. Experiments in Zambia, Nigeria and elsewhere have confirmed the need to apply boron fertilizer in such areas, and in Zambia heavy standard applications of from 57 to 144 g of borate (14% B) per plant are given, the quantity depending on site. Boron deficient crops will produce no saleable yields but *E. grandis* with borate often reaches a mean annual increment of over 25 $m^3$/ha.

A great deal of work has been done on fertilizer application to pines, particularly phosphates (Waring, 1973), and some of the findings have fairly wide application. With *P. radiata* in Australia it was found that for maximum production it is necessary to fertilize at planting and to control weeds. Early responses to fertilizer were still evident at canopy closure and increased with time up to at least 25 years without additional stimulation. Delaying fertilizer application can appreciably reduce productivity. The quantity, time and type of fertilization, type and quality of site preparation and degree of weed control interact to influence early response and consequently total production. Optimizing these various factors offers good management an opportunity to maximize increment. In Nigeria, an application of 114 g of phosphate was found to increase both survival and growth of *P. caribaea* (Jackson, 1974), and in Western Australia zinc fertilizers improved the growth of *P. pinaster* plantations.

Nitrogen deficiency is a limiting factor on some sites, often on abandoned and degraded fields or in areas of drifting sand. The addition of nitrogen-rich compound fertilizers, urea or organic manures is required to get the trees away to a good start on such sites. There is, however, a danger of acidifying certain soils by excessive application of urea or other nitrogenous fertilizers. Sometimes nitrogen-fixing tree crops such as alders (*Alnus* spp.), and many leguminous species are grown either as pioneer nurse crops or as an understory in admixture with the main tree crop. Lucerne and other herbaceous legumes grown as green manure can also be used to raise nitrogen availability in the soils.

## Mycorrhizae

Most forest trees have mycorrhizal fungi associated with their roots and it is thought that trees will not thrive unless satisfactory symbiosis with one or more kinds of mycorrhizae has developed. As a result, the practice of inoculating nursery soils with mycorrhiza-infected soil from forests or plantations has become widespread. Instances have been reported from East Africa and from Latin America of unthrifty plantations of tropical pines which have been restored to health and vigour following soil inoculations by cultures from areas where the pine is indigenous or has become well established. Many species of *Araucaria* are reputed not to thrive as exotics unless both the ecto- and endotrophic forms of the mycorrhizae normally associated with their roots are present in the soil.

Recent research has shown that in very fertile soils tree roots tend to have a much more limited association with mycorrhizae or none at all; accordingly the application of fertilizers also seems to reduce the dependence on symbionts. It has not yet been fully established whether the mycorrhizal association is essential for the development of trees, or whether the association is developed by the tree as a device for increasing nutrient availability in less fertile sites. In recent years, much research has centred on comparing the effects of different species of mycorrhizal-forming fungi, often with notable success. Marx and Bryan (1975), for example, have shown that *Pinus taeda* seedlings inoculated with *Pisolithus tinctorius* grew better on harsh, infertile, disturbed sites with periodic high soil temperatures than did seedlings inoculated with *Telephora terrestris*, the more common and typical pine nursery inoculum in the southeastern United States. *P. tinctorius* also holds promise as a pine inoculum suited to high tropical temperatures; in Nigeria, Momoh *et al.* (1977) found it was able to withstand higher temperatures than *Rhizopogon luteolus*, the general mycorrhizal fungus in use.

## TENDING OPERATIONS

Tending operations are those required to promote conditions favourable for the survival of the plants after planting and to stimulate a healthy and vigourous growth until the plantation is established. On most plantation sites, tending is mostly concerned with preventing the plants from being suppressed by competing weed vegetation. Other tending operations are watering or irrigating the plants in dry areas; in some cases pruning or tree shaping may also be necessary.

## Weeding

Weeding in plantations may generally be defined as a cultural operation eliminating or suppressing undesirable vegetation which would, if no action was taken, impair the growth of the plantation tree crop. Weeds compete with the tree crop for light, water and nutrients, and weeding should increase the availability of all or the most critical of these elements to the planting crop. The main objective of weeding is to promote the growth and development of the plantation crop, while keeping the costs of the operation within acceptable limits.

The main factor affecting the intensity and duration of weeding is the interaction between the tree crop and the weeds. On some sites the tree crop would eventually grow through the weeds, dominate the site and become established; and on such sites the main function of weeding is to increase crop uniformity and speed up the process of establishment. On other sites, the type or density of the weed growth is such that in the early stage of a plantation it will suppress and kill some or all of the planted trees, and in such areas the main purpose of weeding is to reduce mortality and maintain an adequate stocking of trees to establishment. When the interaction between the tree crops and weed growth has been determined and understood, plantation management will have some understanding of the general principles of weeding and of the options open in relation to frequency and duration of weeding; some of these are:

1) Most crops would benefit from a form of total weeding, but very often this is neither feasible nor can it be economically justified.

2) With tree species to some degree tolerant of weeds, a range of weeding intensity may be applied down to the level that will just achieve satisfactory establishment.

3) Tree species intolerant of weed growth require high intensity weeding until the tree crop has taken over or dominated the site.

Clean weeding is not confined to the tropics. In northern Italy, for example, industrial plantations of Pinus strobus are clean cultivated mechanically during the establishment phase. (Courtesy Instituto Nazionale per Piante da Legno, Torino)

Other principal factors affecting weeding are rainfall, temperature, initial crop spacing, size of plants, rates of growth, weed species and density, ability of the weeds to regenerate, such site features as fertility, moisture availability and slope and the skill of the manpower available for weeding.

## Methods of Weeding

The main methods of weeding are suppression and elimination; both can be done manually, mechanically or by chemical techniques. Weed suppression is effected by physically beating down or crushing the weeds or by cutting or screefing the weeds back at or above ground level. Weed elimination is achieved by killing the weeds, either by destroying the whole plant by cultivation or by the use of chemicals. Weeding may be total or partial; the main partial methods being spot or line weeding.

### Weed Suppression

The simplest method of manual suppression is to trample or beat the weeds down, away from the plantation trees. This operation may be mechanized by using a tractor-towed roller, but such an implement cannot operate too close to the tree crop.

The most common manual method of weed suppression is to cut them back using a variety of cutting tools such as sickles, brush hooks and scythes. In many countries cane knives or matchetes are used, and although such tools may not be ideally suited for particular vegetation types, they are used with great skill and the labour need not adapt to a change of tool.

There is a wide range of mechanized cutting weeders, such as:

1) The portable brush cutter, as noted in Chapter 1;

2) The pedestrian controlled two wheeled machines such as the reciprocating bladed autoscythes or similar machines with rotating blades or flails;

3) Tractor powered machines for brush cutting, mainly rear-mounted and operated from the power take-off:

   a) horizontally rotating chain swipe machines,

   b) horizontally rotating blade machines and

   c) vertically rotating flail machines.

### Weed Elimination

Weeding by cultivation generally requires that the weeds, including the roots, are dug out of the soil and are either laid on the surface or are chopped up and worked into the soil. In addition to eliminating weeds, such cultivation may increase rainfall percolation and reduce evaporation from the soil, features which are of considerable significance in certain areas with a marked dry season.

Manual weeding cultivation is done mainly by long handled straight hoes or, in the tropics, by shorter handled recurved hoes. The operation is usually more effective if the hoe is used for actual cultivation involving turning over of the soil, rather than scraping-off of the weeds. As total manual cultivation requires high and costly labout inputs (e.g. Nigeria 25 to 30 man-days/ha) the operation is usually confined to spot or line weeding. In spot weeding a circular area 1 - 2 m diameter is hoed around the trees; in line weeding a strip about one metre wide is hoed along the planting line. Weeding costs are reduced in taungya plantations, where the farmer in tending his crops gives full or partial weeding cultivation over the area during the growing season.

In certain areas with a marked dry season, such as savanna, it has been found that spot or line weeding is insufficient to give adequate plantation survival or growth, and a system of mechanized total cultivation on suitable flat or gently sloping sites has been developed. Total cultivation for large-scale plantations involves mechanized interrow weeding and supplementary hand weeding close to the plants. The only totally mechanized cultivation is the pre-planting harrowing which although classed as a land preparation operation, also serves the same purpose as a weeding carried out immediately before planting.

There is a wide range of mechanized equipment for weeding cultivations including powered two-wheeled or oxen drawn cultivators for small-scale operations; the main weeding equipment for larger scale work includes:

1) Agricultural tractors with rear-mounted heavy duty offset disc harrows and

2) Agricultural tractors with rear-mounted rotavators.

The disc harrows are widely used and, except in areas of exceptionally heavy weed growth, have proven satisfactory in practice. The rotavators also give good cultivation and can deal with heavier weed cover than harrows, but being more sophisticated than harrows, are more prone to damage, unless operated with care and skill.

When interrow weeding is in one direction only it is supplemented by line weeding, when in two directions it is supplemented by spot weeding. Line weeding requires a labour input of some 60% more than spot weeding. Mechanized cross weeding, however, results in some 66% of the interrow area being cultivated twice. One major disadvantage of cross weeding is that the tractor has to cross at right angles the furrows made earlier by the harrow, and the consequent pitching and shock loading can seriously increase wear and tear on the unit.

Total and partial weeding using chemical herbicides have and are being extensively developed. The types of herbicide commonly used for weeding are included in those listed for site preparation in Chapter 1. The essential feature is that experiments are necessary to determine types of herbicide and methods of application, suited to particular plantation species and sites. The main methods of application include:

1) Hand operated knapsack sprayers,

2) Motorized knapsack mist blowers,

3) Granular herbicide applicators,

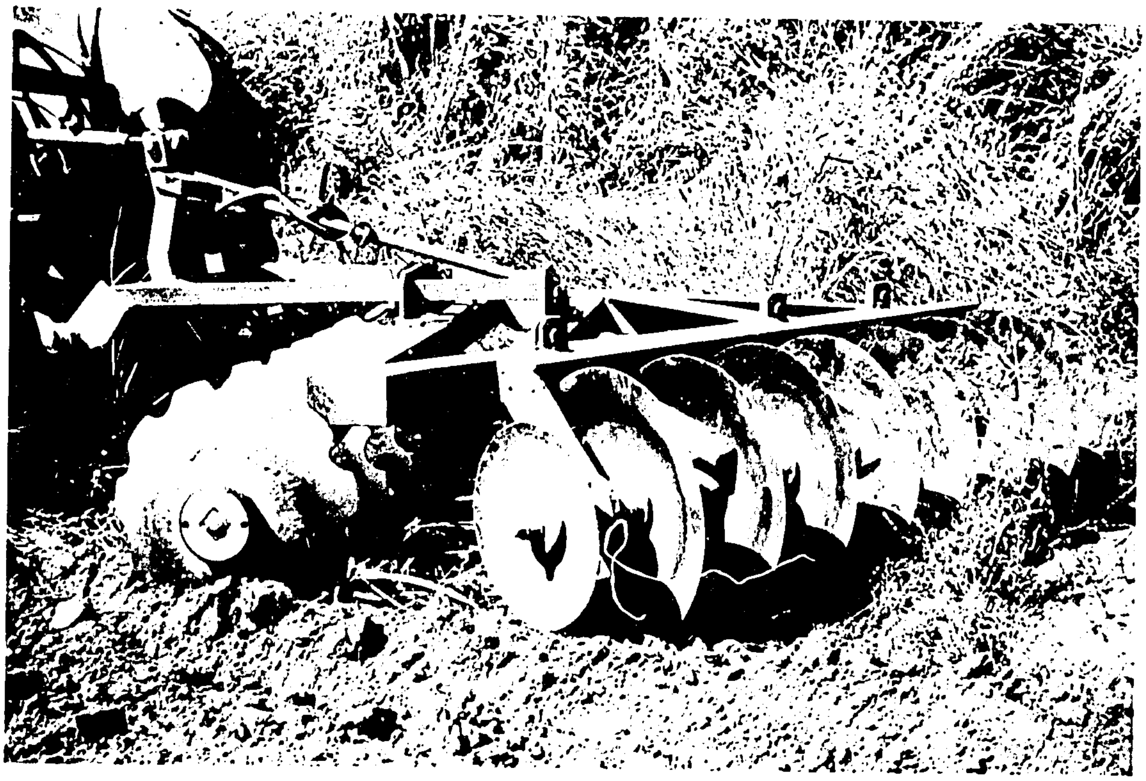
4) Tractor-mounted mist blowers and high volume sprayers,

5) Ultra low volume sprayers and

6) Aerial application.

The selection of type of herbicide application is largely a matter of scale and experience. The development of ultra low volume sprayers has generally widened the possibility of herbicide use. Aerial spraying is feasible for some large-scale plantations; it is extensively used, for example, in New Zealand where some 25 000 ha, or 87% of the annual weeding programme, was done by this method (Chavasse and Fitzpatrick, 1973).

A wheeled tractor with a rear-mounted disc harrow is used for interrow weeding young pine and eucalypt plantations in African savannas. (Courtesy T.G. Allan)



## Types of Weeding Regime

In temperate regions where partial weeding by cutting or chemicals is done, it is common practice to do summer weeding once each year until the plantation trees top the weeds. This can involve a weeding programme of from two to five years. Poplars, for example, require weeding in the two to three years following planting. A common temperate practice is to cut the vegetation and lay a mulch of 1.2 to 2 m around the tree each season.

In savanna regions a common mechanized schedule for eucalypts would be:

| Time of Operation | Type and Number of Weedings |
|---|---|
| First year regime (age 0 to 8 months), during the rains | 6 mechanized interrow weedings in alternate directions supplemented by 5 spot weedings |
| Second year regime (age 12 to 20 months) | 1 to 4 mechanized interrow weedings, with no hand weeding necessary |

A similar regime would be used for pines but the duration would be three to five years instead of two. Both eucalypts and pines in the tropics grow during the dry season at which time the quantity of soil moisture is restricted and the clean weeding regime should increase the water availability to the plantation trees, particularly during the initial year when root development is taking place.

## Watering and Irrigation

Plantations in arid and semi-arid regions often need watering periodically during the first growing season to obtain a satisfactory survival rate. Watering should begin sometime after the cessation of rains when the moisture content of the soil has fallen to near the wilting coefficient and should be repeated at intervals until the onset of the next rains. Before each watering the trees should be hoed clean of weeds and a shallow basin made round the stem of each tree. Where evaporation is high, a heavy watering (20 litres or more per tree) at relatively long intervals is more effective than more frequent light waterings.

Watering is usually an expensive operation, especially on terrain too steep or too rough for the passage of tank vehicles so that pack animals are required to carry drums of water to the plantation site. Watering is uneconomical for large plantations, especially if the source of water is at some distance away from the plantation, but it may be justified in the case of small amenity plantations or for establishing roadside avenues. In many semi-arid countries, regular cultivation and weeding, especially during the first growing season, has proved sufficient to conserve enough soil moisture for satisfactory survival of the plants, obviating the need for watering.

In the case of irrigated plantations, regular periodic irrigation of the whole plantation is the principal routine tending operation, and may continue until the end of the crop rotation. Irrigation channels need weeding at intervals to prevent weed growth impeding flow rate. Spraying channel banks with herbicides, repeated at fairly frequent intervals before the weeds grow too high, is an effective method of control. Irrigated plantations are discussed more fully in Chapter 4.

## Pruning and Shaping

With the exception of very widely spaced crops, pruning is not a normal operation during the establishment phase. However, with certain species of tropical pine, for example, *Pinus kesiya* and *P. oocarpa*, a basal pruning may be necessary to remove adventitious and undesirable branches at ground level. Occasionally pruning may also be carried out not so much to improve the quality of the timber, but to allow access or to reduce the possibility of fire spreading from ground level to the crown.

Tree shaping operations, including the excision of double leaders, are practised in certain plantations, particularly those grown from stumps or cuttings. Such work may very often be combined with climber cutting operations.

The early pruning of side branches and adventitious branchlets is customary in wide-spread poplar plantations where the trees are expected to provide peeler logs for match-making or veneers. Normally the boles are clean pruned up to one-half the total height of the stem for the first five years, thereafter gradually reducing the crown proportion to about one third of the total stem height. Adventitious branchlets, which tend to appear each spring on the pruned section of the bole, are trimmed off as soon as possible after their appearance. Pruning of larger branches is best carried out in the spring before the sap rises; this also appears to accelerate occlusion of the wounds. Pruning wounds or bark damage caused by weeding operations can be treated with formulations of lanoline plus indolacetic acid or lanoline plus Agrosan (an organo-mercuric chemical) which hasten occlusion.

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# CHAPTER 4

# SPECIAL TECHNIQUES FOR DIFFICULT SITES

Chapters 1 to 3 were concerned with site preparation and planting methods primarily on firm ground of gentle terrain where soil moisture was neither excessive nor so limiting as to require irrigation or the construction of special water-retaining structures. This chapter describes techniques which have been developed for particularly difficult sites : 1) areas where soil and water conservation measures are critical factors for forest establishment, 2) irrigable sites, 3) sand dunes, 4) waterlogged sites and 5) mine tips and soil dumps.

## SITES WHERE SOIL AND WATER CONSERVATION MEASURES ARE CRITICAL FACTORS IN FOREST ESTABLISHMENT

This section is concerned with two distinct sets of environmental conditions having one important factor in common - the need to retard or prevent the runoff of rain water falling on the ground. The two environmental categories are sites prone to erosion and arid sites. The need to combine soil and water conservation techniques with tree planting is a characteristic common to both site types. Soil and water conservation techniques are age-old; although in modern times many new techniques have been developed, first using manpower but recently using mechanized methods to an ever-increasing extent.

### Site Conditions and Runoff

#### Sites Prone to Erosion

These are areas with eroding or erodible soils, generally with moderate to steeply sloping surfaces, which are from time to time subject to rainfall intensities capable of producing surface runoff in amounts damaging to the soil structure in the catchment areas. Excessive runoff can also lead to downstream damage in the form of siltation and destructive inundations.

Land subject to severe erosion occurs commonly in the hilly or mountainous parts of those climatic regions with sharply differentiated dry and rainy seasons but also in areas with extensive and heavy rainfalls. In areas with a marked dry season, the surface soil layers tend to become dry and compacted and less able to absorb the rainfall at the onset of the rainy season. Even when the soil has become recharged to field capacity, occasional high intensity precipitation during storms can exceed the soil's capacity for infiltration, percolation and disposal through subsoil drainage, resulting in surface runoff in concentrations which cause soil erosion.

A dense ground cover of permanent vegetation is the best form of protection for soils in such environments. The aerial parts of the vegetation offer physical obstruction to heavy rain and rapid runoff, while the roots and humus-rich horizons facilitate infiltration and absorption of the rain water into the soil. The total destruction of this surface cover for arable cultivation or by persistent burning soon leads to conditions of severe soil erosion and the depletion of catchment efficiency with the concomitants of degraded soils, reduced farming yields and floods. The removal of litter and vegetation for fuel is another factor contributing to soil degradation. In such conditions the restoration of the vegetation cover - usually, but not necessarily always by afforestation - becomes a sine qua non for the control of erosion and further prevention of site deterioration.

## Arid Sites

The arid and sub-desert areas are characterized by a long dry season and annual rainfall as low as 10 to 200 mm. Such areas are more or less sparsely vegetated with deep rooting, xerophytic shrubs, bushes and low trees. The rainy season is usually short in duration, but rainfall, when it comes, often takes the form of high intensity storms giving high surface runoff, so that a large volume of the water is lost in flood spates. The development of techniques capable of holding a large proportion of this runoff in the soil has made possible afforestation with trees of greater economic interest than the native xerophytes in certain areas such as North Africa. South of the Sahara in the Sahelian zone, the establishment of trees at rainfalls of 200 to 500 mm presents tremendous problems except for a few exceptional, favourable sites.

## The Problem of Surface Runoff

The basic aim of soil and water conservation is to create conditions wherein rainfall, or water from snow melt, can be held and encouraged to percolate directly in the soil. In other words, the object is to reduce runoff to a minimum, provided that water for reservoir storage is not a problem.

In regions of abundant or adequate rainfall, soil moisture may be adequate to support both a tree crop and a more or less dense cover of ground vegetation. On such sites, afforestation requires a minimum disturbance of the existing ground cover sufficient only to enable the introduced tree crop to grow without harmful competition. In this situation, the problem is to control runoff and soil wash until such time as the new forest cover can develop its own capacity for soil protection. The extent and costs of preliminary soil conservation works can often be reduced if the native ground cover can be intensified by protection from such destructive factors as cultivation of unsuitable sites, excessive grazing of domestic livestock or persistent burning. In Cyprus the total exclusion of goat grazing from burned-over forest areas in the mountain lands resulted in so dense a regrowth of the indigenous shrubs and maquis vegetation in the course of two or three years, that the previously applied and costly soil conservation works could be dispensed with almost entirely.

On arid sites the emphasis is more on the need to collect and retain rain falling on the plantation site for utilization by the forest trees during the growing season. In such circumstances the competition of existing vegetation for limited soil water reserves can prove critical, so that afforestation techniques on arid sites favour clean cultivation and water retaining structures.

The objective of all soil conservation and water retention techniques is to induce or to maintain conditions of maximum water infiltration, absorption and disposal through subsoil drainage. Each site will have an optimum water absorption, depending on the vegetative cover, the surface litter and the texture of the soil through all horizons to the underlying bedrock formations. Conservation techniques should aim to restore the water retaining capacity of the site to its optimum level. During heavy precipitation, rainfall intensity often exceeds infiltration capacity and water begins to run off. Conservation measures should, therefore, be designed to store in reservoir form as much runoff water as possible and to provide for the safe disposal of any water which is surplus to the created reservoir capacity. Under certain conditions, particularly on mudstone slopes or unstable soils, increased water retention is liable to result in landslips, and on such sites certain water conservation measures could prove harmful.

The design of conservation measures, their capacity and complexity and, therefore, their cost will derive from the terrain and from the forecast of rainfall amounts and intensities as compared with the water retention capacity of the site. Such rainfall forecasts can be reasonably accurate if long term data (including rainfall intensity records) are available for the area together with runoff data, as recorded by experimental runoff plots and local stream flow gauges. In the absence of such data the forester will have to design the conservation plan on the basis of the best local experience available, as the time available for investigation and research is often limited.

The less detailed or reliable the information and data are for making estimates of peak runoff from a given site, the greater the emphasis should be on the inclusion of drains and other devices for diverting surplus runoff into controlled discharge drains.

## Soil and Water Conservation Methods in Regions of Good Rainfall

A great deal of technical experience has been recorded on the subject of erosion and on soil and water conservation techniques. The intention here is to discuss briefly those measures which are commonly employed in combination with afforestation.

### Revegetation

In areas where rainfall is sufficiently plentiful or well distributed through the year to maintain a relatively lush ground cover of indigenous species, the first step to be taken is to ensure the protection of the site from any form of use reducing the effectiveness of this natural vegetative cover.

The most commonly encountered destructive factors are fires, overgrazing, and shifting cultivation. Protection against such forms of damage nearly always involve disruption of traditional methods of land use and the introduction of new systems of land management. Such changes may provoke hostile reactions from the communities affected unless social problems are identified and analyzed and acceptable solutions found. In the example from Cyprus mentioned earlier, the land set aside for afforestation consisted of hilly forest reserves traditionally grazed by livestock owned by fringing communities. The herdsmen, usually a landless minority community, in return for agreeing to abandon forest grazing, were compensated by grants of agricultural holdings, sometimes excised from other parts of the reserve, or by grants in cash sufficient to enable them to set themselves up in some other form of employment. With the cessation of grazing, the fire hazard was greatly diminished.

In Cyprus a solution to overgrazing was relatively simple; other countries facing similar erosion problems are evolving other solutions suitable to their varying conditions. In Yugoslavia the abolition of forest grazing was greatly assisted by planned industrial development which was able to absorb the migrating forest grazing communities. In Greece and Turkey more emphasis is given to the development of improved range lands and the introduction of high-productivity livestock as indirect compensation for the closure of other sectors of the catchment destined for afforestation.

In South Korea the national encouragement of community self reliance and the development of village forests is proving an effective way of reforesting marginal, eroded hill lands. In Thailand the setting up of forest villages, together with the provision of land for cultivation and cash benefits from afforestation work, is reducing shifting cultivation by offering the cultivators a settled and higher standard of living. In Indonesia, the provision of cash subsidies and the development of a fodder/forest cash crop system has persuaded farmers to initiate the reforestation of steep catchment land which they had previously cleared but found unsuitable for long-term cultivation.

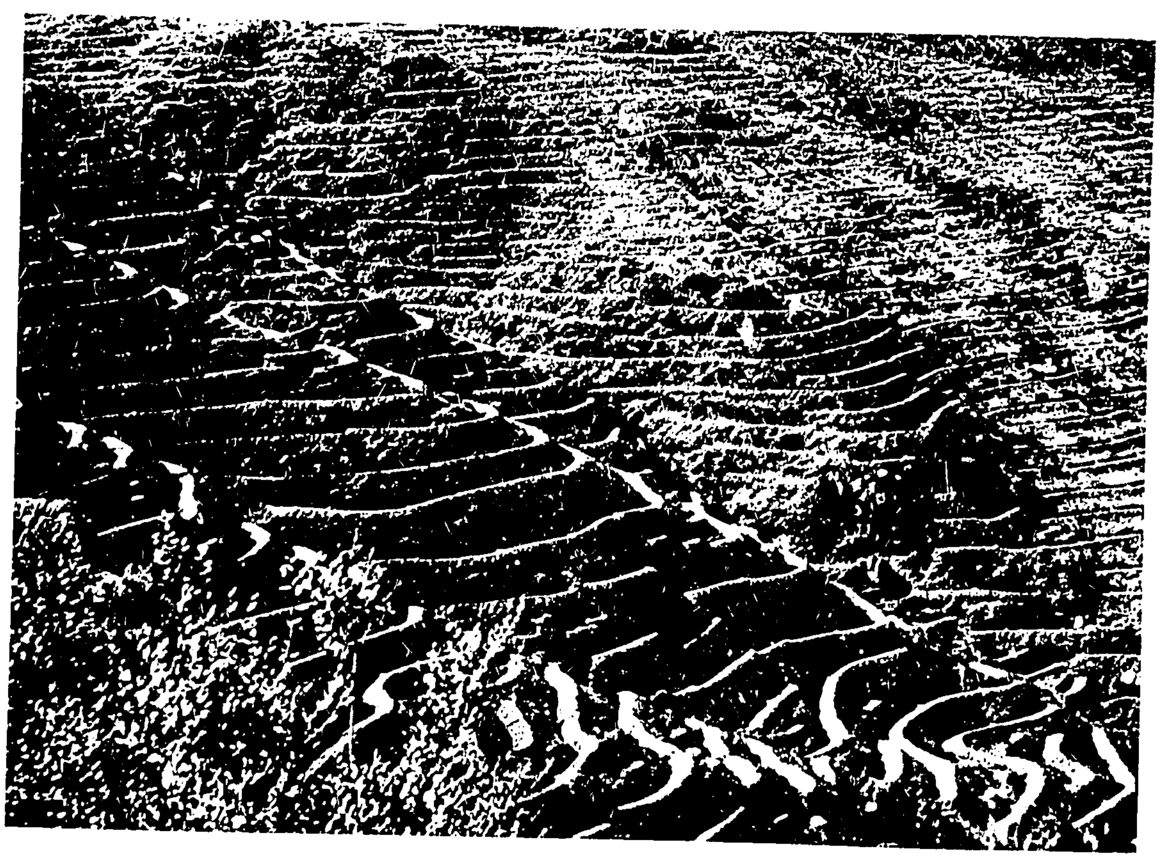
The exclusion of grazing and shifting cultivation by legal or administrative action has rarely proved successful unless accompanied by some acceptable compensatory measures.

Water and Soil Retaining Structures

The underlying principle of such structures is to contain or retard the flow of rainwater off the ground as it falls, preventing surface runoff water from accumulating in volumes sufficient to cause damage to the land by scouring.

Terracing

The age-old method was to level the land in a series of steps down the mountainside, the steps being supported by terraced walls of unmorticed masonry where stones were abundant on the site; on sites lacking stones the terraces were supported by earth banks or bunds protected by natural vegetation. Modern techniques, as described recently by Sheng (1977), are mostly adaptations of these ancient soil conservation works.



Construction of narrow contour terraces is a common site preparation technique on steep, erodible slopes in northwestern Turkey. (FAO photo)

Contour Steps and Ditches

Contour steps (i.e. gradoni or banquettes) consist of a ledge dug out of the hill slope along the contour, the outer edge of the ledge or step being raised above the inner edge. The contour ditch differs from the contour step only in having a more pronounced basin and bank effect when viewed in profile.

Contour steps or ditches can be designed so that their water storage capacity matches the expected runoff from the strip of land immediately above them, to the next contour work above. Alternatively, for any fixed design capacity, the frequency of the contour steps or ditches - or the width of the interval between them - can be related to the expected maximum intensity runoff. Several formulae for calculating the size and frequency of contour ditches and steps exist. Saccardy (1950 and 1959) working in Algeria used the following formula:

$$\frac{H^3}{S} = 260 \pm 10$$

where H is the vertical interval between contour ditches or banks, and S is the degree of slope in percent.

A similar formula used in Sri Lanka, among other countries, is:

$$H = \frac{30}{4n} \ (n+9)$$

where H is the longtitudinal distance in metres between contour banks and n is the degree of slope in percent.

In areas liable to erosion the distances in the table below are given as a guide to the spacing of contour terraces, steps or ditches.

Table 1: Distance between contour works according to slope

| Slope (Percent) | Distances in metres | |
|---|---|---|
| | Vertical | Horizontal |
| 3 | 2.0 | 67.0 |
| 6 | 2.5 | 42.0 |
| 10 | 3.0 | 30.0 |
| 15 | 3.4 | 23.0 |
| 25 | 4.0 | 16.0 |
| 35 | 4.5 | 13.0 |
| 50 | 5.0 | 10.0 |

The steeper the slope, the greater the vertical distance between lines and the smaller the horizonal distance. This is computed in proportion to the rainfall catchment area between lines of contour works.

Contour ditches and steps are usually constructed by hand, using pickaxes or grubbing hoes. Lines 10 m to 40 m long and 1 m to 1.5 m wide can be constructed per man-day depending on the design and size of the ditch or strip and on the terrain, vegetation cover and soil structure. Contour steps of 2.3 m width can also be constructed mechanically, even on slopes up to 60%, using crawler tractors fitted with angledozers. This method is used extensively in Algeria and in Cyprus, where the contour strips are called "catastrips". Subsequent subsoiling along the catastrip increases the capacity of the soil, and hence the effectiveness of the entire operation.

On easy slopes (below 25%) where the soil is often deeper, contour ditches can be constructed by a tractor-drawn share plough, turning the soil downhill.

An example of the comparative costs per hectare of afforestation and soil conservation is provided by data reported from Tunisia where both manual and mechanized methods are in general use. There the manual construction of 550 - 600 linear metres of contour steps per hectare required 235 man-days of labour. The same work was done by machine in one day, at one-third the cost. The full costs in 1966 of plantation establishment are shown in Table 2.

Table 2: Costs of Afforestation Combined with Soil Conservation Works in Tunisia (1966)

In US Dollars (1 Dinar = US$ 1.90) and Man-days (m/d)

| Work Item | By Hand | | By Machine | |
|---|---|---|---|---|
| | With Banquettes | With Steps | With Banquettes | On less sloping land |
| Clearing vegetation | $ 123.98<br>150 m/d | $ 123.98<br>150 m/d | $ 93.88<br>126 m/d | $ 62.32<br>80 m/d |
| Construction of banquettes (550-600 linear m per ha) | $ 177.13<br>235 m/d | | $ 57.90<br>1 m/d | |
| Construction of steps in broken lines (800-1000 linear m per ha) | | $ 73.44<br>105 m/d | | |
| Sub-soiling | - | - | $ 41.80<br>1 m/d | $ 32.30<br>1 m/d |
| Construction of access roads | $ 17.95<br>13 m/d | | $ 13.63<br>5 m/d | |
| Cost of planting stock | $ 45.16<br>22 m/d | | | |
| Transport and planting | $ 31.16<br>40 m/d | | | |
| Tending and replacements | $ 45.36<br>25 m/d | | $ 49.16<br>25 m/d | $ 39.33<br>20 m/d |
| TOTAL | $ 440.00<br>485 m/d | $ 337.00<br>355 m/d | $ 332.00<br>220 m/d | $ 224.00<br>168 m/d |

To be effective it is essential that the location of the ditches be aligned accurately using surveyors' levels and that the ditches be subsequently constructed exactly on the pegged lines. Nonetheless experience has shown that it is difficult to construct lines of steps or ditches exactly on the contour, however accurately pegged out, with the result that where errors have occurred, water accumulating in these slight dips in the line sooner or later overflows, creating just the sort of damaging runoff which the system seeks to eliminate. Damage resulting from minor deviations from the contour can be mitigated to some extent by the construction of septa across the ditch or step, which in effect divide the ditch into a series of compartments or basins, increasing the amount of water retention on lines having a slight downward inclination.

Inaccurate construction, especially on difficult terrain or where the workers lack the necessary skills, has been frequently encountered, and this has led to the introduction of alternative systems incorporating occasional graded ditches between "broken" lines of contour ditches and steps (i.e. <u>éléments de banquettes</u>).

<u>Varying Grade Contour Ditches</u>

One method of overcoming the danger of accelerated erosion arising from faults in the levels of contour ditches is to construct at intervals down the slope a series of graded ditches designed to evacuate runoff water from the hill face to specially constructed discharge points in the beds of natural drainage channels. The inclination of the drainage ditches should be 0.5%, increasing in stages of 1.0% towards the discharge end. The length of these graded trenches will depend on the topography, but it is advisable to keep the length as short as possible. The greater the length, the larger and the more costly must be the cross-section dimensions. Lengths exceeding 500 metres should be avoided, if possible.

These graded ditches must be pegged out and constructed with considerable accuracy. Their frequency and location must be decided partly on consideration of the estimated quantities of runoff water and partly to avoid rocky outcrops or other obstacles lying on possible courses. The main disadvantage of the graded ditch is the absolute necessity to maintain the channel in good condition by removing at frequent intervals accumulations of debris, earth and stones which may be washed into the ditch after heavy storms. If such maintenance is neglected the channel will become choked and will spill its water at the point of blockage down the unprotected hillside, possibly overwhelming the whole system of downhill ditches and thereby adding, sometimes spectacularly, to the erosion problem the ditches were designed to control.

The maintenance difficulty, experienced in many afforestation projects, where labour and supervisory staff may have to be concentrated in other areas of the project, has tended to limit the use of this system to the incorporation of an occasional line of graded ditches as a kind of safety-valve with other types of conservation works.

<u>Broken Contour Line Techniques</u>

These have evolved from the contour ditch or step method previously described and include the digging of planting holes or steps on the slopes between the contour lines. In their simplest form, they would consist of a number of steps 0.6 to 1 m square, hacked out of the hillside at distances dictated by the plantation spacing prescribed. A few seeds or a single plant are put in each square.

When the plantation spacing is relatively dense, these square steps are elongated laterally along the contour to provide short distances of steps or ditches, leaving short intervening stretches of untouched vegetated land. The row of trenches or steps next below would be staggered in such a way as to catch runoff water passing through the gaps in the line above. This method has been extensively applied in Morocco and Algeria where the broken lines of steps are called <u>éléments de banquette</u>. This method has the advantage that very accurate levelling can be dispensed with, since it relies on a multiplicity of small steps or ditches to provide protection against runoff and soil erosion. Even where unbroken contour ditches or varying grade ditches are used it is often necessary to prepare planting holes or short lengths of steps or ditches between the main contour works, in order to maintain a more or less regular plantation espacement.

A variation of the broken line system, generally known as the "crescent method", consists of digging a small basin from which trenches lead out laterally at a slight upward inclination, concentrating rainwater runoff in the basin. The tree is usually planted above the basin. The crescent method is particularly applicable on drier sites and with relatively wide planting espacements.

Tied-Ridging Method

This method is an adaptation from an agricultural system of water conservation practised in East Africa, resembling the North American "basin-listing" method, by which the entire surface of the land is covered with basin-like furrows scooped out along the contour with a special plough. In the East African tied-ridge system as applied in afforestation, the land is first ploughed or hoed and then ridged up in lines 2.5 m apart roughly along the contour, these ridges are "tied" by secondary ridges constructed at right-angles to the main ridge lines at intervals of 3 m, forming a series of basins, which are capable of trapping a sudden 50 mm storm. In compacted soils this method has proved superior to sub-soiling due to the fact that the whole rainfall is trapped and utilized. Its application however is limited to flat or gently sloping land.

Wicker Work Fences

On steep slopes where the soil is unstable and liable to creep, the construction of contour steps and ditches may merely serve to increase instability or even to accentuate the rate of earth slip. In such situations the implantation along the contour of rough wicker work fences can help to stabilize the soil temporarily until permanent fixation is achieved by the roots of planted trees and a cover of invading vegetation. These fences are constructed by driving a line of wooden pickets of some durable species into the ground at about 1 m intervals and weaving between the pickets a mass of branchwood. The height of the wicker fences above ground level varies between 0.5 and 1 m. In Japan unstable slopes are sometimes mulched with rice straw pegged into the ground to completely cover the strips between the wicker fence lines.

On unstable soils or stony screes, wicker work fences are often useful, but these sites are generally too impoverished to plant without further treatment. It may be necessary therefore to import good loam or forest soil from elsewhere to fill in the planting holes to give the young trees a good start, but this, of course, is a costly operation. A cover of wire netting can also be used to hold and stabilize scree slopes.

Ravine and Torrent Control Methods

On sites where erosion has reached an advanced stage, it is common to find the land deeply dissected by ravines and gullies excavated by runoff water from the slopes. Unless stabilized by vegetation or by the mechanical action of check dams, such ravines gradually become deeper through the scouring action of the water flows, which also undermine the banks causing their collapse and a gradual lateral extension of the ravine. Actively eroding ravines should be stabilized at the same time as the hill slopes, otherwise they can eventually destroy the effectiveness of conservation measures constructed on the planting sites. Heede (1977) has described the construction of gully control works.

Wherever contour steps or ditches cross ravines, the banks of the ditches will require strengthening by stone revetments; but in the case of ravines exceeding one square metre in cross-section, it is advisable to stop the contour works some metres from the edge of the ravine to guard against the possibility of the ravine banks eroding outwards and "tapping" the contour work.

Where graded ditches discharge into a ravine it is essential to avoid cascading the water into the ravine, since this will result in the ditch channel being eroded back. Where stones are available a masonry check dam should be constructed across the ravine to a height level with the bank of the contour ditch and more or less continuous with it. The water from the ditch can thus flow into the ravine behind the check dam without cascading. The wall of the check dam should be provided with an outlet spillway at the top and a masonry apron at the bottom to prevent water undermining the foundations of the dam wall.

When building check dams the following points should be noted:

1) The foundations should be strongly made and bedded into rock;

2) The ends should be revetted well into the banks of the ravine to prevent water seeping round the wall, eventually causing a collapse;

3) The downstream face of the wall should be given a pronounced back-slope (1:2 inclination from the vertical if uncut stones or boulders are used; 1:3 for dry-masonry walls of roughly cut stones; 1:4 to 1:6 if cement masonry or cast cement walls are used). The upstream face of the wall can be vertical but it should be filled up with rock and debris to the level of the spillway;

4) A spillway must be incorporated in the top centre of the dam wall, sufficiently large to pass the maximum torrent flows expected. The spillway should be constructed of large flat stones, preferably cemented together in the top course of masonry.

To ensure thorough stabilization of the ravine, a series of check dams should be constructed from top to bottom; the dams being so spaced that they complement each other's effects. This rule can be relaxed to allow a slope of not more than 5 percent to build up in the torrent bed between each pair of check dams.

Check dams may be constructed of 1) logs and fascines set across the ravine and held in place by posts driven well into the soil, 2) of masonry (where suitable stones are available), 3) of gabions (galvanized steel wire netting "baskets" or "sausages" filled with stones and pebbles), or 4) of reinforced concrete. Brushwood check dams are useful in small gullies, particularly if the brush includes a species capable of vegetative reproduction and if the upstream side of the dam is well sodded. The choice of material used for check dams depends on the following factors:

1) The slope of the ravine bed and its cross-section dimensions, hence the volume and velocity of the torrent flows to be controlled;

2) The type of construction material most convenient to the site, and

3) The value of the land, including lines of communications, habitations etc., situated below the ravine and which the stabilization works are required to protect. Under some circumstances the cost of ravine stabilization may exceed the value of the protection gained, in which case some compromise needs to be struck in the planning stage. This compromise may take the form of confining stabilization work to the smaller branch ravines, and reducing the number of the larger and more costly structures in the main ravines.

## Water Conservation Measures on Arid Sites

Successful afforestation in very low rainfall areas (down to 200 mm) depends on securing maximum absorption and retention of sporadic rainfall by the soil in the areas to be occupied by roots of the trees. The spacing between trees will generally increase with decreasing rainfall. Land between tree rows which is not expected to be occupied by tree roots in the future can be regarded as water catchment areas for the planted zone. It follows that any indigenous vegetation should be eliminated so as to minimize competition for soil moisture, except on sites where such denudation could lead to wind erosion of the exposed topsoil.

### Contour Banks

One method of site preparation designed to meet the basic requirement of maximum water storage for afforestation on arid sites consists of forming a series of large banks or bunds sited accurately on the contour and constructed of earth and stones scraped off the catchment zones above each line of banks. The forest trees are planted either on, just below or just above the banks.

In most cases, and especially where the soil is compacted or a hardpan occurs near the surface, deep subsoiling or ripping should be carried out prior to the construction of the bank. The subsoiled band should be broad enough to extend on either side of the bank to loosen the soil throughout the tree root zone. The existing vegetation should be eliminated by grubbing, hoeing or disc-harrowing and should be spread as a mulch round the trees after planting.

The height of the contour banks is determined by the estimated quantity of runoff to be contained after each heavy rainfall. Where there is a possibility of high intensity rainfall, the banks should be provided with devices for spilling surplus water into prepared channels or drainage ways. These safety-valve spillways should be strongly constructed to resist the scouring of breaches in the banks and should be large enough to allow an ample safety margin to cope with storm runoff flows.

The construction of such extensive earthworks is too arduous and too costly to be carried out except by heavy earthmoving machinery.

Under arid conditions tree planting in simple holes without water conservation measures rarely succeeds, unless facilities exist for watering or irrigating the trees throughout the dry seasons until the plantations have become fully established.

### Méthode Steppique

In recent years the increasing availability of specialized agricultural and heavy machinery has enabled foresters in arid and sub-desert zones to attempt afforestation projects in areas formerly considered technically unplantable. Some of the most spectacularly successful arid zone afforestation has been accomplished in Morocco and Algeria, where techniques have been developed under the name méthode steppique.

Under the most favourable site conditions in these countries (i.e. on relatively deep, level or gently sloping soils with annual rainfall of 300 - 500 mm spread over five winter months), site preparation is confined to deep subsoiling with a heavy rooter fitted with 2 or 3 tines penetrating to depths of 60 - 80 cm. The area is subsoiled in continuous lines in one direction, and sometimes by passing the machine in criss-cross lines. The subsoiling loosens the soil to such an extent that all rain water is absorbed. Trees are then planted at spacings of at least 3 x 3 or 4 x 4 m. Under certain conditions, subsoiling may be dispensed with altogether, it being sufficient to cultivate the land with agricultural implements to break up the soil surface and to destroy existing vegetation. Most of the extensive *Eucalyptus* plantations in the Marmora region of Morocco were established in this way.

More commonly, subsoiling is accompanied by the construction of banks or ridges 0.5 to 1.0 m in height with bases 2.0 - 3.0 m wide. These banks are pushed up by heavy crawler tractors (150 - 230 hp) carrying bulldozers or angledozer blades. The smaller 0.5 m banks are made by traversing on the contour with an angledozer, returning on the same line with the blade angle reversed. The larger banks are made by bulldozing soil from the land lying above the line of bank in a series of backward and forward movements. The strips between the banks may be further subsoiled if necessary. On gentle slopes, the banks are often made in broken, staggered rows, forcing surface runoff downhill in a zig zag direction through the staggered gaps, effectively spreading the water for improved absorption by the soil.

Although in some areas, for example Cuba (Masson,1973), subsoiling is done on slopes up to 40%, the practice is generally confined to slopes of less than 25%. The method used for steep slopes is the construction of narrow terraces cut into the hills by angledozers (e.g. the "catastrip" method used in Cyprus described on page 84). A subsoiler can be subsequently passed along the bed of the terrace once the angledozer has completed forming the terrace.

Trees are normally planted partway down the slope of the banks corresponding to the original soil level. The mass of loose soil forming the bank favours easy penetration by the tree roots, and experience has demonstrated that trees planted on the banks grow considerably better than those planted on land which has only been subsoiled.

In areas subject to strong desiccating winds it has been found expedient to plough deep furrows (in Algeria the single share mould-board plough is preferred) and to plant the trees in the bottom of the furrow. This provides good shelter from the wind during the first one or two seasons. A combination of banking and deep furrowing provides even better protection from the wind.

Emphasis must be laid on the necessity for removing all vegetation from the plantation area and for keeping the surface clean weeded for two or three years after planting until the trees are well established. The xerophytic vegetation is usually deeprooting and has a strong and persistent capacity for re-sprouting. It is, therefore, essential to uproot this vegetation as far as possible by disc-ploughing or harrowing or by hand grubbing where the vegetation contains a high proportion of woody species. Hand grubbing is laborious and expensive; mechanized clearing is easier, and for this, specially adapted subsoilers (rasettes) are available which are fitted with a forward projecting cutting blade spanning the points of the subsoiler's tines. As the tractor progresses, this blade passes horizontally under the ground and severs the roots, turning up the stumps in the wake of the subsoiler. The root plough attachment for crawler tractors has a similar function but with the primary purpose of cutting root systems.

The main site preparation in eastern Morocco is subsoiling, using very heavy tractors (230 hp) pulling 7 - 10 ton rooters capable of breaking up crusts and hardpans to depths of 70 and 80 cm. The construction of banks is usually omitted, except on the limited areas of deep soil free from hardpan where a large plough capable of opening 50 cm deep furrows is used to throw up contour ridges on which the trees are subsequently planted. Over most of the zone, the large plates of rocky crust turned up by the rooters are such as to make mechanical cultivation of the surface impracticable. The trees are planted in basins made by hand at the intersection of the subsoiled lines. Special care is taken to keep all plantations clean-weeded for two years, either by wheeled tractors with disc-harrows where ground conditions permit, or otherwise by hand. These plantation methods have enabled Pinus halepensis plantations to survive a year of extreme drought when no more than 64 mm rainfall was recorded.

## IRRIGATED OR IRRIGABLE SITES

### General Considerations

Irrigated tree planting is generally associated with arid sites where the annual rainfall rarely exceeds 200 mm or with semi-arid sites, where the rainy period is short, both resulting in long periods when soil moisture is deficient. Under such conditions, indigenous forest growth is either absent or limited to xerophytic species with very deep taproots and strongly developed transpiration control mechanisms. Such areas have an extremely low productivity and are usually of limited economic interest.

Some desert or sub-desert lands, however, have proved suitable for the production of economic forestry crops using irrigation. Notable developments of irrigated tree plantations exist in the Sind Desert of Pakistan, in Iraq, in Egypt and in central Sudan.

Apart from the desert or semi-desert regions, irrigation has also been associated with the culture of poplars, and to a lesser extent of willows, in regions characterized by a relatively high winter or seasonal rainfall alternating with a pronounced dry summer season, such as in the higher altitude districts of the Mediterranean and in countries with continental climates. Under these climatic conditions, the soil moisture regime is normally not a limiting factor to tree growth, except for such fast-growing species as poplars, which require moist soil throughout the year.

Growing forest trees under irrigation has developed from row and ornamental plantations in agricultural areas, and most forest irrigation methods have adapted methods used for the field crops grown in the same locality. However, in recent years forest research has questioned the advisability of following these agricultural methods too closely. Some of the questions to be answered by research into irrigated silviculture are:

1) The optimal yearly consumptive use of water (i.e. crop water requirement) for each species, that is, the quantities and timing of water needs. The water requirement varies with climate and species and even for different provenances within a species;

2) The best methods of applying the water to the land, giving due consideration to such factors as conveyance loss, deep percolation as well as future weeding and thinning, and the exploitation of the crop;

3) The response of indigenous and exotic tree species when grown under irrigated conditions.

### Plantations in Irrigated Agricultural Projects

Due to the high cost of initial establishment, irrigated plantations will only be supported in a few regions where there is a serious lack of wood or where other considerations, such as prevention of erosion or desertification have to be taken into account. Most often, irrigated forests will only be considered as a by-product of an already existing scheme, and under such conditions the extra cost of irrigated wood production can be kept within an acceptable range. However, where forest plantations are established in irrigated agricultural projects, the irrigation layout will normally have been designed to suit the rhythm of field crop cultivation. The forester is thus obliged to adapt his methods to this rhythm, which may not be ideal for growing trees. Many irrigated agricultural systems are also based on a certain crop intensity; however, forest plantations may need water more or less continuously through the year, therefore the areas suitable for irrigated forestry are best located on sites accessible to the main arterial canals which carry water throughout the year.

Sometimes irrigation water is cut off for considerable periods of the year depending on the seasonal flows of source rivers, the storage capacity of reservoirs or on water usage rights operating downstream. In Pakistan some irrigation schemes in the Indus Plain provide water for only six months of the year; for the rest of the year crops depend on residual soil moisture. Treaty arrangements between Egypt and the Sudan limit the water withdrawal from the Nile River during certain periods of the year in the Sudan. In the Gezira irrigation project and others dependent on the Nile water, no irrigation water is available at all for three and one-half months (mid-March through June) during the hottest time of the year, which means that only tree species capable of adapting to this intervening drought period can be used.

Most of the older irrigation projects were designed for agriculture without thought of forest crop production. As a result, forest planting was often relegated to sites unsuited for field crops or adjacent to the tail end of irrigation canals. On such sites water supplies are often irregular, sometimes in excess - leading to waterlogging - and at other times deficient when the water needs of field crops take priority.

In some more recent irrigation projects, the need for amenity planting, lumber, and, more particularly, fuel wood for the project communities has been recognized.

Irrigated Afforestation Projects

Although most irrigated afforestation work is assocated with existing agricultural schemes, sometimes an irrigation system is created solely for production of forest plantations. In northern Iraq, for example, a number of plantations have been established in "Ahrash" scrub lands forming broad strips along the banks of the river Tigris and its tributaries; these are irrigated by water pumped from the river. Similar plantations exist in the "Gerf" areas flanking parts of the Nile in the Sudan.

In this type of project the forester is responsible for the layout, construction and operation of the whole irrigation system and though this involves engineering skills outside his normal training, it has the great advantage that he is able, generally with some expert assistance, to design a system to suit the special needs of the tree crops.

The Influence of Soils

Two soil characteristics govern the choice of an irrigation method and also the quantity of water applied and the frequency of irrigation. These are the rates at which water will enter the soil (infiltration rate) and the capacity of the soil to hold water for use by the crop (waterholding capacity). Sandy or gravelly soils are most easily penetrated but hold much less water than a medium or heavy textured soil.

The presence of a water table can also provide a reservoir of soil water for the tree roots, and once they reach this depth they can grow without or with much less irrigation, provided salinity is not a problem. For example, in the Khartoum greenbelt afforestation project, the heavy clay soils restrict water percolation through the surface layers so that an intervening dry layer between the groundwater table and the wetter surface zone prevents tree roots reaching the water table.

Salts are always present in the soil and in irrigation water. If these salts are allowed to accumulate in the upper soil they can damage and prevent the growth of crops. During irrigation, additional water is necessary to ensure that these are leached below the crop root zone. The danger of such salinity is also acute where drainage problems occur. Wherever the soil is saline it may be necessary to plant only those tree species known to be tolerant of soil salinity; it may also be necessary to equip the project area with a complementary system of drains capable of drawing off the salts dissolved in irrigation water. Where saline soils exist, it is advisable to leach these out prior to planting. In certain cases it may be possible to grow a field crop such as barley, during the leaching period which can help to offset the costs involved.

The foregoing underlines that a thorough soil survey is an essential prerequisite for designing the irrigation layout and for selecting the species to be planted.

## Irrigation Methods

Of all irrigation systems, surface irrigation is the cheapest and the one best adapted to tree crops. It can be practised by using either the basin, furrow or border methods, of which the first two are most commonly used for plantations. In the flood or basin system, the water is spread evenly over the surface of the ground; in the furrow system the ground is wetted by lateral infiltration.

### Flood Basin and Border Irrigation

The basin method is most suitable on gently sloping land with a more or less even surface. It consists of a series of medium-size basins with 20 to 30 m sides surrounded by earth bunds. The basins are filled up one after the other with 10 to 20 cm of water depending on the soil's water-holding capacity.

The border system of irrigation is similar to the basin method but is designed for smooth sloping surfaces. Rectangular plots 15 - 30 m wide and 100 - 150 m long are constructed in the direction of the main slope. The plots are separated by earth bunds 20 cm high. Ditches run along the upper edge of each plot, and the water flows down the whole surface into the drainage ditch at the bottom.

Another variant of basin irrigation is very frequently used for poplar cultivation in mountain valleys, where the land is levelled in a series of terraces following the contour line. The water enters at the top of the series and each basin is successively irrigated from spillways constructed in the bunds of the terrace above.

### Furrow Irrigation

In this system furrows are constructed leading off from the feeder channel in parallel lines spaced at sufficient intervals to wet the tree rooting zone. The spacing between furrows and their capacity therefore depends on the permeability of the soil.

Poplars respond well to irrigation. Those shown here on the Rhab Plain, Morocco, are four years old. (FAO photo)

As a general rule the heavier the soil the larger and the wider apart the furrows will be; the opposite applies in more porous soils. In the heavy clay soils of the Khartoum greenbelt plantations, the furrows are normally spaced at 2.5 m intervals, but following recent investigations it has been found that adequate wetting of the root zone can be obtained by furrows 6 m apart.

This system has special application in elevated areas within irrigation projects too high to be reached by the normal gravity flow irrigation. Provided the ground is not more than about 1 m above water level, deep and wide furrows are made, and the trees are planted on the sides or banks of these furrows. This method is used in Iraq, especially for plantations of pomegranates and other fruit trees, as well as for plantations of Eucalyptus and Casuarina. However, the digging of such deep furrows by hand is costly. Another major disadvantage of this method in forest plantations lies in the obstruction the furrows offer to the passage of tractors and implements, for example, during inter-row weeding operations. Such a sub-irrigation system can also cause severe waterlogging and salinity problems.

Trickle or Drip Irrigation

Trickle or drip irrigation is a modern, complex, precise method of irrigation which is being developed for agriculture and horticulture but has recently been adapted for the establishment of tree crops in areas where there are adequate financial resources to meet the high costs. The main benefits of this method are that it reduces water loss, produces good crop responses, optimizes fertilizer use and results in less weed growth. In experiments in Pakistan, drip irrigation used only 22 percent as much water as furrow irrigation and 15 percent as much as flood irrigation. The main limitations are the high costs compared with furrow irrigation; the high level of skill required for design, installation and operation; moisture distribution problems including the sensitivity of equipment to clogging, and salinity hazards (FAO, 1973).

Trickle or drip irrigation is a watering system where water is distributed to points without atomization and without soaking the land. The density of the watering points can be arranged to allow the selected subsoil to be suitably moistened, while the greater part of the surface soil remains dry. Water delivery is by polyethylene or other forms of plastic pipes fitted with "drippers" or "tricklers" which deliver a suitable flow at low pressure, normally within the range of one to two atmospheres. The pipe system is often buried in the soil to apply moisture at prescribed rooting depths, but under certain conditions it may be on the surface, allowing easy removal when necessary. Clogging of drippers is a common problem, and there are a number of approaches and types of drippers to reduce this difficulty.

## Water requirements of tree crops

Water requirement is the depth of water needed to replenish the available moisture in the root zone, depleted by evapotranspiration. The water required to enable a forest plantation to grow at optimum rate will vary from season to season; it will increase with each succeeding year of the rotation until full crown cover has been attained. If the groundwater table is close to the surface, requirements will diminish once the roots have reached the ground water. Like agricultural crops, different tree species have different water requirements, depending largely on their transpiration control mechanisms.

Crop water requirement, whether of agricultural of forest crops, can be computed using the following formula:

$$ET\ crop = Kc.\ ETo$$

where ET crop is the crop water requirement in mm over a given period of time (i.e. the evapotranspiration when soil water supply is non-restricting); ETo is the reference evapotranspiration in mm over the same period; and Kc is the crop coefficient. For a fuller description of the method see FAO 1977a.

Reference evapotranspiration (ETo), is defined as "the rate of evapotranspiration from an extensive short green cover completely shading the ground and adequately supplied with water". Empirical formulae have been devised for calculating ETo. Common methods are (i) the Blaney-Criddle method which is used when only temperature data are available; (ii) the radiation method which is used when available climatic data include measured air temperature and sunshine, cloudiness or radiation; (iii) the Penman menthod which is used when measured data on temperature, humidity, wind, and sunshine or radiation are available.

Crop coefficient (Kc). Crop water requirement is affected by several factors including crop characteristics, stage of growth, and the prevailing weather conditions. Values of Kc have been established for vegetable and fruit tree crops. Using the Kc values for fruit trees as a guide, a rough estimate of the coefficient for low-transpiring trees would be about 0.5; high-transpiring trees would have a coefficient around 0.9 or more. For example in subtropical climates with winter rainfall, ETo is about 1,000 - 1,300 mm/year, and the crop coefficient for low-transpiring fruit trees such as citrus reaches a maximum point in June-July of around 0.7; ET crop would then be approximately 700 - 900 mm/year. Olive trees, which are well known for their very low transpiration, would have an estimated crop coefficient of 0.4 - 0.5, and the ET crop would consequently be somewhere between 400 and 440 mm/year. High-transpiring tree species may have considerably higher Kc values. The water requirements for optimum growth of forest crops have been inadequately studied.

## Irrigation requirements of tree crops

The main purpose of irrigation is to prevent lack of water from limiting tree growth. The net irrigation water requirement of a tree crop can be computed by the following formula:

$$In = \underbrace{ET\ crop}_{(losses)} - \underbrace{(Pe + Ge + Wb)}_{(gains)}$$

where

In = net irrigation requirement (mm/period of time)
ET crop = crop water requirement ( " " " )
Pe = effective rainfall ( " " " )
Ge = groundwater contribution ( " " " )
Wb = stored soil water at the beginning of each period.

Effective rainfall (Pe). Not all rainfall is effective as part of the water is lost by surface run-off, by deep percolation, and by direct evaporation. That part of the rain which penetrates the soil and is effectively available to the trees is defined as the effective rainfall. Effectiveness of rainfall depends on its intensity, amount and frequency.

Groundwater contribution (Ge). Groundwater can contribute to the supply of water to trees when it is within reach of the roots. It is therefore useful to determine the depth of the watertable in relation to expected tree rooting depth. Watertable depth often varies seasonally, and seasonal measurements are therefore required. When the groundwater table is close to the surface, e.g. in valleys, mature trees generally do not require irrigation; in such cases irrigation may only be needed for the establishment of young plantations, and can cease when the roots of the trees reach the watertable.

Stored soil water (Wb). The storage capacity of the soil is the quantity of water available; it ranges between field capacity (soil water tension 0.2 atm.) and wilting point (15 atm.). The quantity of water that can be stored depends on the soil texture; heavy soils store some 200 mm/m, medium textured soils some 140 mm/m, and light textured soils some 60 mm/m or less. It will be noted that use of the above formula will, theoretically, cause Wb to be zero for all successive irrigation periods except the first.

In irrigation, the rate of soil water uptake by the trees and the storage capacity of the soil play a very important role in determining the depth and frequency of applications. Heavy soils may receive large applications at extended intervals, whereas light soils require smaller applications at more frequent intervals.

Relatively little research on net irrigation requirements has been carried out for forest plantations. In Pakistan, experiments have shown that the optimum amount of water for Dalbergia sissoo (the most important plantation species) lies between 900 and 1,350 mm, applied at fortnightly intervals through the six-month irrigation period. The non-availability of irrigation water during the other six dry winter months limits the selection of species to those which have an extended period of dormancy.

In the Sudan, investigations on net irrigation requirements in Eucalyptus microtheca plantations in the black cotton soils of the Gezira indicate that 2,400 mm per year, applied in 13 irrigations, give good results. The irrigations are made at fortnightly intervals during the period July to December when irrigation water supply is unrestricted, and at 6 week intervals from January to March when water is in short supply. From mid-March to June no irrigation water is available under the Sudan-Egypt agreement. The rainfall, which is 230 - 450 mm per year, falls mostly in the summer months from July to September. Investigations carried out in the Khartoum greenbelt indicate that best growth results when annual irrigation is about 750 mm/ha/year, although mean annual rainfall is less than 200 mm. Higher irrigation rates lead to waterlogging in the heavy alkaline clays in this area, and to reduced growth.

In Turkey, scientists working at the National Poplar Institute calculated the water requirements for poplar plantations at a large number of stations located in the different climatic regions of the country; the calculations took into account precipitation, normal shade temperatures, humidity, Gaussen's Coefficient, and calculated global radiation. Irrigation is normally necessary between May and September, increasing gradually up to July and August (the hottest and driest months), and thereafter decreasing. The highest water requirements of about 1,000 to 1,100 mm, for the six-months irrigation season, occur in the Diyarbekir region in southeastern Turkey. No irrigation is needed at Rize (in the north-east Black Sea coastal region) where well distributed annual precipitation averages 2,440 mm and exceeds the calculated maximum evapotranspiration. For most poplar plantations in Turkey net irrigation water requirement is between 500 and 700 mm.

The above figures refer to net irrigation requirements. Gross irrigation requirements may need to take account of leaching requirements (additional water required to flow through and beyond the root zone in order to prevent salinity build-up) and of the efficiency of the delivery system.

## Response to limited water availability

Very little is known of the comparative response of different tree species to limited availability of soil water. Most studies have been related to "optimum" levels of irrigation to produce "optimum" growth rate. In many dry areas it may be necessary to limit water availability at certain seasons to less than the "optimum". More research is needed on the response of different species to depletion of soil water, expressed as a reduction in the rates of transpiration and of growth.

## Planning the Layout of Irrigated Plantations

As already noted, forestry is usually ancillary to agriculture in irrigation schemes, and the setting up of irrigation purely for plantations is an infrequent occurrence. Planning and designing the layout of an irrigation project is a highly skilled, precise and demanding task, and it is necessary to call upon high expertise and specialist advice if an adequate and successful project is to be prepared.

Following is an outline of some of the factors influencing the layout and extent of irrigated plantations:

1) Gross area commanded by the main canal. This is composed of (a) the gross irrigable area, where irrigation can be developed and (b) the non-irrigable area, all land which is unsuitable for irrigation. The gross irrigable area is composed of the net irrigable area and the area needed for the roads, water channels and buildings.

2) Availability and seasonal variation of water supply in relation to the estimated water requirement of the species selected.

3) Quality of the irrigation water, particularly as regards the quantities of salts or other toxic elements.

4) Topography. The most suitable sites are on level or gently sloping land. Steeper slopes or land with many undulations and surface irregularities add to the complexity of the water distribution system and the cost of levelling work. A detailed topographical survey with 1 metre contour lines is an essential preliminary to planning the layout of the whole project.

5) Soils, with particular reference to their permeability, chemical status and ground water formation.

The main layout plan should delineate on the topographical map 1) the course of the main canal from its head, or water intake point, to the highest point commanding the lands to be irrigated, 2) the direction of the main branch canals within the boundaries of the total area commanded and 3) the location and extent of enclaves of land unsuitable for irrigation or planting. A detailed soil survey map should be imposed on the topographical map. Finally, the layout of future plantation compartments and irrigation blocks should be determined so that the delivery capacity of the branch canals serving each irrigation block can be correlated with the areas watered, the periodicity of irrigation and the water need of the species planted.

Preparation of the Land and Construction of the Canal System

After clearing of existing vegetation, the whole area should be roughly levelled. The object of land levelling is to reach a good uniformity in water application by an even flow of water over the soil surface. However, as tree crops seldom support the extra cost required for full land levelling, it is recommended that lands be chosen with a slope as even as possible and that levelling be limited to a simple operation of smoothing out only the main irregularities.

The next operation is to mark out and construct the main distributor channels and the road network. Bulldozers and graders, if available, are suitable for levelling and for pushing up embankments. Channels can be opened by double mould-board drain ploughs or by excavators, depending on the size of the channel required. Finally, the network of smaller channels feeding each compartment or plot much be constructed.

Before planting, it is essential to carry out trial or test irrigations to expose any faults or low places in canal and channel networks and also any areas within the compartments in need of further levelling.

Flow Capacities in Irrigation Channels

The rate of delivery of water in a channel is a function of its cross-section dimension, its grade and the smoothness of the surface of the channel bed and sides. The flow is usually expressed in "cumecs" (cubic metres per second) or "cusecs" (cubic feet per second)(1 ft$^3$ = 0.0283 m$^3$). There are various forms of gauges which can be installed in the channels to measure delivery rates, but in the absence of these a method of estimating is to multiply the cross-section area of the channel up to the wetted perimeter (the part of a channel which is wetted by the flow of water) by the flow velocity (obtained by stop-watch timing of a floating cork over a measured distance of channel). This will give the volume of water passing a given point per second. This nominal figure must then be diminished by multiplying by a coefficient representing the drag on the flow exerted by the roughness of the side of the channel. This coefficient will depend on the smoothness of the walls and of the dimensions and gradient of the channel. As a rough guide the coefficient for a channel with a gradient of 1 to 5 000 would be about:

| | |
|---|---|
| Concrete lined channels | 0.80 |
| Clean earth channels | 0.70 |
| Channel walls, grassed-over | 0.60 |
| Channels obstructed by fairly dense vegetation | 0.50 |

In the case of unlined channels the coefficient also includes allowance for losses by seepage.

Sluice Gates, Off-take Regulators and Syphons

All distribution channels require sluice gates or off-take regulators constructed at all points where subsidiary channels branch off. These are preferably constructed in concrete or masonry but are sometimes made of wood. The simplest construction consists of a sliding gate which can be raised or lowered to control the volume of water entering the subsidiary channel.

Concrete syphons are used at road crossings whenever irrigation channels are at the same or at higher elevations than the roadway.

Pumped Irrigation

Situations occur when land destined for irrigated plantations lies above the level of the water source. The water must then be raised by pumps to the level of the main irrigation canal.

Irrigation pumping usually requires large flows under low heads. The pumps best suited for this kind of use are of the propeller or mixed-flow type. They can lift from 1 $m^3/s$ to 10 $m^3/s$ or more under heads of 3 to 10 m or more if several stages are used. Several pumps, preferably of similar design, should be used to provide the total flow needed for the irrigated area, and if these operate on a 24 h per day basis, an extra pump should be on hand in case of breakdowns. These pumps usually have a very good overall efficiency. Their rotation speed is low and they are able to operate for long continuous periods of time without damage. Their wear is very low and they consequently have a long lifetime of up to 20 years. The propeller or mixed flow pumps are large and must be installed in sturdy pumping plants especially constructed and adapted to the type of pump used. In the upper part of the plants the engines are located on a very strong floor to support their weight. Underneath comes an intermediate level composed of various vertical casings through which the water flows up and out of the station. The lower part is where the large pumps are installed. The individual impellers must be at a sufficient depth below the minimum water level to protect the pumps from the formation of vortex and from cavitation effects on the blades. Intake grids should be installed in front of the pumping plants to keep any large floating matter from entering and damaging the pumps. Likewise there must be gates to isolate each pump for maintenance or repair purposes.

Much smaller pumps can be used for very small irrigated areas. They can be either of the vertical or horizontal type, but in the latter case the intake pipe should be as short and as close to the water as possible. Check valves should be installed at their foot to reduce any problem of suction.

Road Networks

The road network must be planned and constructed simultaneously with the irrigation channel system, so that the number of bridges, culverts and syphons are kept to a minimum. All main canals and distributaries should be provided with roads to allow access for canal maintenance operations, and no roadside avenue trees should be planted which might subsequently impede the passage of canal clearing machines, a precaution that is frequently overlooked.

## Establishment Costs of Irrigated Plantations

Establishing an irrigation scheme is always very costly. At 1966 costs simple surfac irrigation would require an initial investment of at least US$ 1 500 per hectare. The major expense item is the cost of constructing the canal and road network, especially if the whole cost of the canal system is included in the forest budget. In existing irrigation schemes for agricultural development, the capital charge for the construction of the main canal and distribution network is born entirely by the irrigation authority, which may or may not charge a rate on the water supplied to the forest authority. In the Indus Desert in Pakistan, forest plantations paid an irrigation water rate per hectare; but in the Sudan, irrigation water in the Gezira and greenbelt plantations, is provided without charge to the forest authority, which is therefore concerned only with the layout of secondary feeder channels within the plantation.

## SAND DUNE SITES

### General Considerations

Vast areas of unstable sand dunes occur throughout the world in all climatic regions wherever regular strong winds and friable topsoils occur. Some areas of sand-drift originate along shore lines with wide strips of sandy beaches, and at times of strong winds the sand is blown inland to form what are called maritime dunes, as distinct from continental dune formations, which have no relation to the sea and usually result from the destruction of the native vegetation by cultivation or overgrazing. Noteworthy examples of continental dunes occur in the "dust-bowl areas" of central U.S.A. and in the semi-arid sandy steppe lands of the lower basins of the Don and Volga rivers in U.S.S.R.

When wind erosion occurs, the coarser particles of sand or soil are carried close to the ground surface, about 90% of the material within 30 cm and some 57% within 5 cm of the surface. These particles move in a series of bumping movements and induce movement in other particles in a type of saltation process. Sand dunes or hillocks form as the blowing sand encounters bushes, trees or some obstruction capable of creating turbulence. This turbulence reduces the carrying force of the wind to both the windward and leeward sides of the obstacle, causing the sand to be deposited in mounds until the obstacle has been completely engulfed in the dune. Dunes extend in the direction of the wind as sand is blown up the windward face of a dune over the crest and again deposited by turbulence on the leeward side. Rates of advance of as much as one metre a month during periods of very high winds have been observed.

Drifting sand can become a menace by encroaching on agricultural land or by blocking canals and lines of communication, or even by engulfing habitations. If, however, the drift sands can be stabilized, experience shows that they can often be successfully afforested and can, under favourable climatic conditions, become very productive. The Pinus pinaster forests in southwest France in Les Landes offer a good example of successful reclamation of a former waste of dunes formed by strong prevailing winds blowing in off the Atlantic in the Bay of Biscay. There are many other examples of successfully stabilized dune formations, e.g. those in North Jutland in Denmark, in Tunisia and in western Libya where the fixation and afforestation of vast areas of both maritime and continental dunes are among the principal tasks of the forest services.

Drift sands, though generally poor in nutrients and often devoid of organic matter, usually hold moisture well. Even in very arid areas, where annual rainfall seldom exceeds 200 mm and is confined to a short rainy season, the sand remains moist at depths of 50 - 60 cm although the surface layers become desiccated by evaporation. An exception is free draining sand, where water percolates rapidly through the soil and under extreme conditions the available soil moisture is insufficient to support tree establishment. The basic problem in drift sand afforestation is to fix the moving sand for periods long enough for the young trees to become established. Once established, the plantation is able to provide its own shelter effect within the planted area and in course of time to enrich the sand with the humus from decaying leaves, providing of course, that sand from outside the area is prevented from engulfing and burying the young plantation. Sand drift stabilization, therefore, involves attempting to provide barriers or windbreaks at the windward source of the drifting sand and thereafter to prevent the sand from movements caused by eddies and turbulence within the zone sheltered by the windbreaks.

Fortunately there are periods during the year in most sand drift areas when the sand is not in movement, when high winds are lulled or when heavy rains give some temporary cohesion to the surface layer. Such periods of rest may be of sufficient duration to encourage the survival of indigenous vegetation, which can spread fairly rapidly over the surface once shelterbelts are provided, aiding considerably in the processes of stabilization.

In very favourable conditions where regular, well-defined high wind periods are interspersed with relatively long intervals of heavy rains and warm temperatures, it may even be possible to stabilise moving sands simply by planting trees of well-adapted, fast-growing species during the wind free periods. Such appears to be the case in the coastal sand-drift areas of southern Viet Nam, where the dunes can be stabilised by planting rows of Casuarina without the necessity of employing any other special fixation techniques.

In general, however, tree planting cannot be successful unless special measures are first taken to prevent or reduce sand movement.

## Sand-Drift Fixation Methods

The first step in sand fixation is to identify the sources of the blown material and, if possible, to create barriers to prevent or check any further invasion of this material. Such primary barriers or shelterbelts will normally have to be repeated in series at intervals downwind from the source area in order to create sheltered zones where the main force of wind is broken up into turbulent eddies having only a localized action on the surface. The second stage in the stabilization process is to protect the surface from this relatively localized scour and deposit effect of air turbulence within the shelter zones. This secondary protection can be achieved by a variety of methods which act, in effect, as surface mulches.

### Primary Protective Barriers

Where coastal beaches are the source of the blown sand, the normal practice is to form a littoral dune along the shoreline. This is done by erecting a continuous but permeable fence of posts, fascines or any other material convenient to the site. As the blown sand accumulates and buries the fence a similar fence is constructed along the top of the dune on the windward side of the crest, and as this is buried in sand a third may be constructed and so on. In a few years littoral dunes can be built in this way up to 10 metres in height. If necessary, several parallel lines of dunes can be constructed along the coast, and the hollows between them stabilized and planted with ground vegetation and belts of trees to form a first line defence against the invading sand. The species used in the first shelter belt should be windfirm and tolerant of salt spray carried in-shore by the wind.

At Waitarere, New Zealand, a belt of Pinus radiata stabilizes coastal sand dunes and protects adjoining agricultural land. Marram grass was planted on these dunes prior to tree planting. (New Zealand Forest Service photo).

The sources of windblown sand forming continental dunes are often less simple to control than in the case of maritime dunes. The sand may be picked up from wide stretches of cultivated plains or, as in the case of North Africa, from rainless deserts, such as the Sahara. The logical first step, therefore, is to try to remedy the conditions causing the exposure of the soil to wind action. This may be accomplished by stubble mulching in grain growing areas, by controlling excessive grazing and by systematic planting of windbreaks in the farm and pasture lands where the topsoils are liable to wind erosion. Even where such measures are not possible, as in the Sahara, it may be feasible by systematic reconnaissance to discover points where the topography causes "wind-funneling" effects. A range of hills may form a barrier to the drifting sand which, however, succeeds in penetrating the barrier at some low-lying point or where streams or torrent beds have cut passages through it. Such points offer possibilities for stabilization by the formation of protective dunes across the direction of the wind using methods similar to those for littoral dunes.

The main objective in creating such barriers or shelterbelts is to reduce the force of prevailing winds to less than 18 - 25 km/h, which is the threshold velocity at which soils begin to move. A great deal of the information acquired in the course of investigations of tree windbreaks in different parts of the world is applicable to drift sand control and stabilization. In general terms these effects may be summarized as follows:

1) The distance that protection extends to leeward is proportionate to the height of the windbreak; when wind direction is at right angles to the line of the barrier, wind speed to leeward is reduced significantly for distances up to 20 times the height of the barrier. The percentage reduction of wind speed varies also with the density of the windbreak and with the distance to leeward. There is also a zone of reduced wind speeds to windward, varying from twice to five times the height of the windbreak;

2) Wide windbreaks are not necessarily more effective than narrow ones; best results are obtained with those which are about as wide as they are high;

3) Evaporation is greatly reduced in the lee of windbreaks, owing to reduced air movement and temperature and increased atmospheric humidity. Evaporation may be reduced for a distance extending up to 24 times the height to leeward of the windbreak. The reduction is proportionate to windbreak density, so that a permeable barrier, especially with a sparse lower level, is not as efficient as a dense one in reducing evaporation. This effect is of particular importance in afforesting sand drift areas in hot, semi-arid regions.

Surface Stabilisation Methods

Even within the shelter afforded by littoral dunes or windbreaks, wind velocities may at times, and in some places be high enough to cause sand movement. The effect of such movement, or sand blast, can be very damaging, especially to newly-planted trees. Eddies of wind may cause localized scouring and deposition so that some of the young trees are either uprooted or are buried in sand. It is, therefore, almost always necessary to blanket the whole area with some sort of mulching or a network of small windbreaks capable of stopping the sand from blowing. In recent years a technique of mulching the surface by spraying with Bitumen emulsions shows considerable promise of success and has been widely used in certain parts of the world.

## Classical Methods

The method in most general use is to cover the whole area with a chequer-board pattern of minature windbreaks, which may consist of stake and wattle fencing made of cut branches or of stiff-stemmed grasses or canes. Sometimes the fences consist of living plants. These fences or hedges vary in height from 0.5 to 2 metre and may be spaced apart from as much as 40 metres to as close as 2 metres, in the latter case only one tree is subsequently planted in each square. When wider spacings are employed, it has sometimes proved necessary to cover the surface of the ground with branches, straw or grass cuttings to give additional protection. Sometimes a surface covering of branchwood is sufficient in itself to stop sand blowing without the need to construct the squares.

In Tunisia all the methods described are used. In spite of the protection of littoral dunes, the maritime dunes are covered with a network of fencing made of cut branches from adjacent maquis forests. Live hedges of Saccharum aegyptiacum are planted in squares of 15 m or 20 m and the soil is then mulched with a layer of branches. In Cyprus, on the other hand, a simple covering of branches was found sufficient protection for plantations of Acacia cyanophylla to survive the first year, after which the plants provided sufficient cover to protect the site. Where conditions are not too severe, direct planting of "stumps" of Acacia cyanophylla has succeeded in establishing a cover without the need of other fixation measures.

This classical method of fixing dunes is usually costly, especially if cut branchwood or cut grass is not available close to the areas to be stabilized. Even where available the large amounts required may mean denuding one area to protect another. Fixation methods using live grasses or tree cuttings often delay the planting of main crop species while waiting for vegetation or hedges to grow enough to stabilize the surface, and once having done so, their roots may spread so far into the intervening space as to compete seriously with the forest trees. Hedges and fences in closely spaced squares also impede the movement of men in the area, especially at tree planting times, and inevitably fences get damaged so that gaps appear causing localized "wind funnel" erosion.

## Dune Spraying Techniques

Spraying shifting sand with fuel oil or bitumen products has been used as a method of fixing blown sand in many countries. Such products are used in the United States and Kuwait, for example, for protecting highways against encroaching sand, and in India and Pakistan for fixing dunes which fill up irrigation canals. In recent years spraying drift sands in connection with afforestation has been developed on a relatively wide scale in Libya and Tunisia. The type of bitumen product used in these countries is available from most of the oil companies. The Pakistan Irrigation Research Institute has recently investigated the stabilizing efficacy of certain of these proprietary products as compared to some similar laboratory-prepared bituminous emulsions. These latter consist of bitumen, potassium hydroxide and potassium carbonates with stearin pitch, vinsol resin soap and 5% bentonite slurry emulsified in water at 95°C. When sprayed on sand such emulsions penetrate the surface layers and dry rapidly to form a crust on the surface which gives complete protection against wind. The depth of penetration varies to some extent with the product used, with the proportion of water in the mixture and with the quantities sprayed per unit area. To be effective, penetrations of 1 to 3 cm must be obtained. The spraying also has the effect of increasing the load bearing pressures of the sand by up to 20 - 30 tons per square metre.

In Libya one company, working on contract for the forest service, has sprayed several thousand hectares of dunes, and similar techniques have been tried in Tunisia. Initially conventional tank trucks were employed which were especially equipped for desert use to carry the oil into the areas to be afforested. The compound was then sprayed over the sand by hand operated lance sprays. To speed up the work the company developed a special vehicle, a steel sled fitted with an 800 litre tank and wide spray booms, which is towed or winched over the dunes by bulldozer. In this way, the spraying equipment can surmount the most difficult dune terrain leaving behind it a sprayed strip 25 metres wide. Each vehicle can cover about 4 hectares a day and uses approximately 4 000 litres of the oil product per hectare. In Libya the spraying was found to have toxic effects on some of the plants used (generally Acacia and Eucalyptus) so spraying now precedes planting. This also enables spraying to be carried out in seasons unsuitable for planting. In Tunisia trials with the same bitumen product indicated that spraying after planting is more practicable, since it was not harmful to the young plants (Acacia and Pinus). In areas sprayed before planting the movements of the men planting and carrying plants to the planting sites caused so much disturbance to the stabilized surface crust that its protective effects were greatly diminished.

Continuing experience will certainly bring improvements in spraying techniques and in the formulation of the stabilizing products used. Combined with the advantages of speed and lower costs, it seems likely that spraying techniques will tend to replace the classical methods of dune fixation. This tendency is likely to be accelerated if experiments in Libya for air-spraying a new type of chemical stabilizer are successful. This stabilizer is a chemical adhesive compound which coagulates when it absorbs moisture and forms a thin stabilizing layer over the surface of the dunes. Seeding of the areas from the air at the same time as the chemical stabilizer could mean a complete revolution in the techniques of afforesting drift sands. Early records indicated that spraying techniques were more cost efficient than the classical method of dune fixation.

## WET OR WATERLOGGED SITES

Wet sites are those in which the soil is waterlogged for the whole or the greater part of the year and can only be afforested if the land is drained.

The vast areas of swamps and fens, supporting natural self-regenerating forests of hydrophytic species of economic value, which occur both in the tropical regions and in the boreal coniferous zone are excluded from consideration here since the tree species have themselves evolved ways of overcoming the difficulties inherent in this environment. However, there are also equally vast areas of swamps and peatlands which are entirely treeless or only carry an arboreal vegetation of low-value species. According to some estimates this area is as great as 200 million hectares. A large proportion of this area could, after drainage, be afforested with species of high economic value.

Apart from these large expanses of bog land, the forester is often faced with relatively small marshy lands occurring as sub-sites in a larger afforestation project on well drained soils. Such local sites may occur in small depressions or on alluvial flats adjoining the banks of rivers, and their drainage may be required as part of the general afforestation plan.

Whether water-logging is a characteristic of the whole area or only of some relatively small section, the techniques for draining away the water and rehabilitating the soils are essentially the same.

### Sites Where Drainage is Practised

#### Marshes with Free-Standing Water

Before soil drainage or soil drying can be undertaken, standing water on the surface must be evacuated. This requires knowledge of the origins of the water coming into the marsh and the reasons for it collecting and stagnating in the area.

In the cases where the water flows from higher land it may be possible, under certain topographic conditions, to intercept the flow at some suitable point above the level of the marsh and to divert it to a cut-off drain or canal leading into some natural drainage channel.

Riparian marshes created by periodic inundations of a river in flood can only be drained by constructing bunds or embankments capable of keeping flood water from entering the riverside flats. It may then be necessary to construct a series of drains in the marsh to dry out pools left in old flood channels or to cope with water entering by underground seepage from the river bed. If, as is sometimes the case, the topography does not allow the evacuation of these drains downstream by gravity flow, it may be necessary to concentrate such water in a sump pond whence it can be pumped back into the river channel over the protecting embankment.

Similarly with lagoon type marshes bordering the seashore, sluice regulators are required on all outlets to the sea, to be closed at high tides and opened again at low tides to allow the marsh water to drain out to sea. Such regulators may be closed by an automatic device, actuated by the rising tide water levels.

A marsh may sometimes owe its origin to the presence of an obstruction to its natural outlet channel caused by geographical faulting, or by land slips or falls of rock. Many upland marshes exist as the relics of former lakes and drowned valleys formed by geological upthrusts damming in the valley. In time, the natural spill-ways are eroded away, gradually lowering the level of the lake water until the water becomes shallow enough for marsh formation. These marshes can be drained by cutting a channel through the obstructing barrier or by tunnelling through it, always assuming the costs are not excessive in relation to the area to be reclaimed.

Some marshes are formed on the low-lying shores of lakes as a result of periodic rises in the lake water level following heavy rains. These can be reclaimed by constructing embankments above the highest water mark of the lake and subsequently draining the marshes by pumping or by the use of regulator sluices on the drain outlets to the lake.

A similar method is employed extensively in low-lying areas in the Paraná delta in Argentina for reclaiming land which is periodically covered to shallow depths by flood waters. Here the marsh lands are encircled by bunds and then drained by pumping, forming a series of reclaimed islands which are then afforested. In the dry season, the pumps are used to pump water in the reverse direction from the deeper marsh water channels for irrigating the plantations.

## Peat Bogs and Gley Soils

Poorly drained peat soils occur mainly in those regions of the world where annual rainfall greatly exceeds evaporation and where temperature is sufficient for a rich production of organic matter but too cold for its rapid decomposition. Under such climatic conditions, an accumulation of plant remains and the formation of peat is common. In addition to climatic factors, level topography and poor water permeability of the subsoil favour bog formation. Swamps and other waterlogged soils are, therefore, fairly common in flat lowlands even in tropical and subtropical climates, although owing to more rapid decomposition in warmer areas, true peat may be missing. On the other hand, under extremely humid and maritime conditions bogs with thick peat deposits can exist even on quite steep slopes, as in parts of Scotland and western Norway.

Waterlogged mineral soils with little or no peat formation also occur in conditions of impeded soil drainage. These are usually heavy clay soils and exhibit the typical mottling discoloration associated with gley soils. Poor drainage may be due to an impervious substratum or to the presence of a podsolized or laterized hardpan.

Even in waterlogged soils the uppermost horizon may be sufficiently aerated to support a ground cover of mosses and other water-loving species; in some cases, this layer may be deep enough to support trees, though these are often deformed with very shallow root systems and liable to windthrow. Early attempts in Great Britain to afforest peat bogs after constructing shallow surface drains proved that the tree crops, while making good growth in the early years, could not withstand strong winds during the pole stage.

It is essential to achieve an aerated layer of topsoil at least 30 cm deep, preferably deeper. To achieve this, drains must be cut considerably deeper to allow for the effects of what is known as the "capillary fringe". This is in effect a waterlogged zone which is formed due to capillary forces just above the level of the true water table or above the level of surface water in the receiving drain. This capillary fringe can sometimes reach as much as 30 cm upwards, which explains why shallow drains sometimes appear to have no effect on waterlogging. To allow for this capillary fringe, receiving drains should therefore be at least 40 - 60 cm deep, and even deeper to ensure the formation of a sufficient layer of fully aerated soil for root development.

Salines and Salt Marshes

Waterlogged soils and marshes occur where high salinity is an additional limiting factor to soil wetness. Salt or brackish marshes formed along the coasts and subject to inflows of sea water are found in many parts of the world. In arid climates, salines can result from the evaporation of salt-bearing spate flows impounded in inland depressions.

Though there are some tree species of economic value, e.g. *Rhizophora* spp., *Tamarix articulata*, *Prosopis tamarugo*, and the date palms, which tolerate a high degree of soil salinity (and in the case of the mangroves, marshy conditions as well), the afforestation of salines is impossible unless the land is both drained and the salt content of the soil reduced or removed by leaching with large quantities of fresh water. This may be feasible in situations where the saline is capable of being drained, so that flood waters entering can be used for washing the salt out of the soil or where irrigation, combined with drainage, may achieve the same effect. Desalination, however, is almost always a very costly undertaking and can seldom be justified for tree crops alone. Further mention is made of this matter in the section dealing with irrigated plantations.

Where permanent drainage is not feasible, the only alternative is to construct a series of alternating mounds and ditches, the soil being excavated from the ditches and spread on the intervening mounds which become plantable once the salts have been leached out over a period of time by local rainfall. Such mounds should be large enough to provide adequate growing space for the expanding tree root systems above the highest level of fluctuations in the water table. This again is a very costly operation and can seldom be justified on economic production criteria.

In fact foresters would be well advised to avoid trying to reclaim marshy areas where the difficulties of site preparation are further complicated by high salinity.

## Drainage Techniques

Drain Characteristics and Layout

For planning the layout of the drainage systems in marshes or waterlogged soils, a detailed topographic survey of the area is necessary. Also, in waterlogged soils, or in marshlands from which free-standing water has been drained, soil formations should be examined carefully so as to identify the type of soil, the depth of any peat layers or the presence and depth of any hardpan formation. Chemical analyses of the soil are needed as a guide to possible fertilizer treatments.

Experimental plots should be established to test the drainage efficiency of different intensities and depths of drains by measuring the movement of the water level in pits located between the drains.

On waterlogged sites, drainage ditches must be constructed prior to planting of most species. The photo shows a vigorous pine stand in Queensland, Australia. (Courtesy D.A. Harcharik)

Three types of open drains are recognized: cut-off drains, receiving or collector drains, and evacuator drains.

## Cut-off Drains

Cut-off drains are designed to intercept water entering the marsh and to lead it to some other line of natural drainage, thus by-passing the swamp. The dimensions of a cut-off drain should be large enough to take the maximum flow of water entering the marsh in times of heavy rains or of floods.

## Collector Drains

Collector drains are those which actually receive the water seeping from the soil; the spacing between collector drains must therefore relate to the percolation rate of water in the soil. The heavier the soil, i.e. the higher its clay content, the slower the percolation rate and, therefore, the shorter the distance between drains. Peat also holds water tenaciously, which means that sites with deep peat layers need very intensive drainage works. On sloping terrain, collector drains should be aligned as far as possible along the contour, allowing just enough downward inclination to induce a flow into the main evacuator drains. In this way the maximum interception is obtained for a minimum length. A drain aligned at a more pronounced oblique angle across the slope will have a steeper gradient and a longer length for the same interception, while a drain aligned at right-angles to the contour loses its interception capacity entirely.

The cross section dimensions of collector drains will be determined largely by the type of soils encountered, but normally they would be at least 40 cm and possibly as much as 1 m deep. The top width of the drain should be at least as great as the depth, and the sides which slope down to the bed should not be less than 20 cm deep and not less than 30 cm in peat to allow for the tendency of these soils to close.

The gradient of the drains (i.e. the downward inclination of the bed of the drain towards the discharge point) should be between 0.25 and 3.0%. Below 0.25% there is a danger of excessive silting and above 3.0% there is the risk of scouring and erosion unless the bed is cut in very resistant soil formations. The required gradient can be obtained either by gradually deepening the drain or, on sloping land, by aligning the drains at an oblique angle to the contour without varying the depth of the drain. This is the method used when drains are constructed by fixed depth draining ploughs.

The length of collector drains should in general fall between 50 and 100 m as in longer drains there are more chances for error in gradient, especially when encountering changes in the direction of the slope. Moreover, the longer the drain the greater the risk of excessive accumulations of water in times of heavy rains.

The distance between collector drains will vary according to the soil type encountered and also the slope of the terrain. As already stated, in general the heavier the soil the closer the drains should be to one another. The standard distances between drains on gley and peaty-gley soils adopted by the British Forestry Commission is 7 m on slopes up to 5%, 10 m on slopes between 5 and 7.5% and 13.5 m on slopes above 7.5%. On less heavy soils, as for example the peaty podsols which characterize certain upland heaths in Great Britain, the spacing can be doubled.

In Sweden, Finland and Russia drains are generally wider apart. In these countries when the drainage of peat bogs was started, drains were constructed 80 - 120 m apart and 1.0 - 1.5 m deep, but experience suggested that these distances were too great to secure efficient drainage. In later years when a change over from manual to mechanized drain digging became possible, distances have been reduced to 20 - 30 m between shallower drains of only 40 - 60 cm depth. On sloping terrain and particularly on waterlogged mineral soils with thin peat layers, the British system of relatively closely spaced drains has been introduced with success. Determining the economic optimum suggests that narrower spacings be used on level swamps than on swamps which are sloping and that wider spacings should be chosen on poor sites and narrower spacings on good quality peatlands.

Evacuator Drains

Collector drains discharge into evacuator drains, whose function is to convey drainage water to some point where it can be disposed of either by discharge into some natural water course or by pumping.

The layout of the system of evacuator drains should be designed to tap as many collector drains as possible. Experience indicates that this is most likely to be achieved by the so-called 'herring-bone' layout with a central main evacuator drain and branch collector drains taking off on both sides.

The dimensions and gradient of evacuator drains are normally greater than those of the collectors; their design should be sufficiently generous to accommodate exceptional flows in times of heavy rains. Their cross-section resembles the truncated V-form of the collector drains.

Other Forms of Soil Drainage

In cases where waterlogging of the soil can be attributed to the presence of an impermeable hardpan, it may be possible to drain the land by breaking up the hardpan with subsoiling implements, enabling soil water to percolate downwards through the breaches in the hardpan. This has proved possible in certain types of coarser textured soils overlying podsolised hardpan in upland heath moors in Scotland.

The effectiveness of drainage work can sometimes be improved by mole ploughing (see page 109), especially in stiff clay soils free of stones. The opening of subsoil drains in this way can speed up the action of collector drains, and in favourable circumstances mole ploughing directly into evacuator drains enables the collector drains to be more widely spaced or to be dispensed with altogether. The British Forestry Commission is now experimenting with some success with the use of a special forest mole plough capable of opening a subsoil tunnel drain in peat beds. This plough extrudes a ribbon of peat 38 x 20 cm leaving only a narrow slot at ground level.

## Drainage Machinery and Implements

The opening of drains by hand, though still used on sites too small to warrant the expense of machinery, has by now been superseded in most situations by mechanized methods. Nowadays, there exists a great variety of drain digging machines, but the two types found most convenient in forestry drainage work are the drainage ploughs and the hydraulic type excavators mounted on wheeled or crawler type vehicles.

Drainage Ploughs

In peat and other soft soils free from large stones, ploughs provide by far the cheapest method of forming drains. The most usual type in use is the double mould-board drainer drawn by a tractor or by a tractor and winch. This plough cuts a V-shaped drain throwing the soil on both sides of the drain. If short wings are bolted to the top of the shares extending laterally and slightly above the soil level, the soil thrown by the shares is pushed well clear of the drain edges, thereby reducing the amount of soil falling back into the drain.

Single share mould-board ploughs are less often used than the double share drainer, but they are preferred in certain circumstances. For example, when cutting contour drains on sloping surfaces it may be desirable to throw the soil out on the downhill side of the drain furrow. In the United Kingdom the single share plough is used extensively for making shallow (20 - 30 cm deep) drains in peaty soils, though the main object of the operation is to provide ridges of peat turves on which the trees are planted. The plough furrows of course also help in draining surface water in times of heavy rain, but they are not normally deep enough to dry out the soil, mainly on account of the effects of the capillary fringe, of which mention has already been made. The British Forestry Commission has developed modifications of this plough capable of cutting deeper drains, some as much as 90 cm deep. These have shown certain disadvantages compared with the double share drains:

1) The full depth of drain is rarely achieved in practice because the enormous side-thrust exerted by the single share in lifting and turning the continuous ribbon of peat forces the plough body up the batter on the side opposite to that on which the soil is placed. This produces an uneven, undulating bed to the drain and results in an uneven edge and batter on the side free from the thrust. A double-share drain, however, maintains a full and constant depth, and the downward thrust of the soil acting equally on both sides results in a better shaped and more stable drain.

2) On mineral soil, where a hard or gravelly layer is sometimes encountered, the same trouble occurs. The single mould-board plough tends to ride up over the harder parts of the subsoil producing an uneven and ragged drain.

3) The single share plough cannot be used to deepen and clean existing drains like the double mould-board drainer.

Ploughing on waterlogged soils usually requires specially designed wheels or tracks for the tractor pulling the plough as well as for the plough itself if loss of traction or bogging down is to be avoided. Wheels and/or tyres are available with a wider tread, or double tractor wheels can be used. Four-wheel-drive tractors, although more costly, have advantages over normal drive tractors under such conditions. Crawler tractors can be fitted with tracks wider than the standard. Ploughs for wet soil should be fitted with steel drum wheels or tractor type wheels.

In Finland, Sweden and northern Russia, peat lands are drained using very heavy (4 - 6 ton) drainage ploughs drawn by crawler tractors of 9 - 18 tons using a winch. These heavy machines have been found superior on sites where the land to be drained consists of swamps with a thin peat layer containing logs and stumps and with a subsoil which is often rocky.

## Mole Ploughs

The mole plough is essentially a single-tine sub-soiler, the digging point of the tine being replaced by a squat torpedo-shaped head, called the mole. In operation this mole opens a tube-like passage through the soil, starting from the drain bank or outlet point and being drawn up slope. Mole ploughs are directly mounted on a tractor, fitted with an Edes linkage which enables a graded channel to be achieved in spite of minor surface irregularities.

Mole ploughing is only effective in even textured clay soils free of stones, but in such circumstances it is the cheapest way of draining the soil. Modifications of the mole using a 15 cm expander have been used in peat soils to speed drainage of water to open collecting drains, and as mentioned earlier, the British Forestry Commission is also experimenting with special mole ploughs for subsoil draining in peat bogs.

The main disadvantage of mole-draining is that the drains cannot be cleaned, so that once they are clogged, the work has to be completely redone.

## Excavators

A great variety of excavating machines are available but most fall into three categories: dragline excavators, hydraulic excavators and continuous action machines.

### Dragline Excavators

Dragline excavators have large excavator buckets operated by machine winches. Draglines are mounted on wide crawler tracks and are particularly suitable for operation on soft or boggy sites. Working on mats further increases stability on soft sites.

Dragline excavators can be used for virtually all types of drainage construction and maintenance work. Their advantages lie 1) in their ability to work on wet sites, 2) in the long reach provided by the boom, which also enables soil to be spread over a wider radius and 3) in the versatility possible in the size and cross-section dimensions of the drain excavated. On the other hand, they are less mobile and more clumsy to handle than the hydraulic excavators which are generally less expensive in operation.

Hydraulic Excavators

With these machines the excavating bucket is attached to the end of a short articulated boom and is operated by hydraulic pistons. The excavators are mounted on crawler or wheeled tractors. Most types are fitted with a dozer blade loader which, apart from occasional use for loading, and the advantage of being able to remove soil banks and other obstructions, is necessary for crossing wide ditches and also serves as a stabilizer.

The wheeled type excavator can be used on most wet mineral soils, but on peat and very soft soils a crawler tractor is essential; it should be fitted with 76 cm tracks or wider. Hydraulic excavators can be used for making drains of those widths and depths commonly used in forestry and can also be used for drain maintenance in wide drains, the machine operating from opposite banks of the drain.

For drain maintenance and cleaning a form of lightweight excavator mounted on an ordinary agricultural type wheeled tractor is available.

Continuous Action Machines

These are excavators fitted with dredging-action chains of buckets or scrapers or with a rotating helix. Experience has shown, however, that these machines have several limitations compared with other types of draining implements regarding the depth and shaping of drains, while most have difficulties in operating in soil where large stones, stumps and roots are encountered. In general it can be said that drain ploughs or hydraulic excavators can do the same work more efficiently and more cheaply than continuous action excavators.

## Post Drainage Site Preparation

### Surface Cultivation

Drainage alone is not always a sufficient amelioration of soil conditions for successful afforestation. In some cases, the porosity and aeration of the soil of drained marshland must be improved by ploughing, and this may have to be preceded by the destruction of herbaceous and arboreal marsh vegetation. Wherever possible this vegetation should be burned and the phosphorus and potassium rich ash ploughed into the soil. If further soil cultivation is unnecessary, seedlings can be notched directly into the drained land. This is the general practice in Finland, but direct broadcast sowing of pine seed is also used to afforest drained peat bogs. In the United Kingdom, direct planting or seeding on drained peat bog has only limited success and the method of notching plants into the turves turned up by ploughing along the planting lines is more commonly used. This method also has the advantage that the strip of over-turned soil retards the growth of competing vegetation for sufficient time to allow the young plants to become established. In warmer climates such advantages of turf or ridge planting are likely to be short-lived on account of the more rapid growth of weeds. A large plough ridge may even prove an obstacle impeding the passage of harrows or rotavators used in subsequent inter-row weeding and ground cultivation work.

Bedding, or the creation of lined mounds, either alone or in conjunction with excavated drains is also used to improve drainage and facilitates planting on wet sites in the U.S.A. As described on page 29, bedding is carried out by heavy duty disc harrows (of the types described for pioneer ploughing) which are set to throw the soil inwards to form a mound, that elevates the planting bed above the general level.

**Fertilization**

Drained marshland soils often show deficiencies in soil nutrients as well as having a strongly acid reaction. Salines on the other hand may often be strongly alkaline as well as being deficient in nitrogen and other soil nutrients. Where the peatlands have not been classified into identifiable types, careful chemical analyses of the soils should be made at an early stage before afforestation to identify which nutrients are in deficiency. Fertilizer trials should also be carried out to determine suitable techniques and application rates to restore soil fertility levels and promote vigorous tree growth.

Nitrogen is usually abundant in marshland soils, though often in an insoluble organic form, but drainage and the addition of mineral fertilizers usually increase the rate of nitrogen mobilization to such an extent that additional nitrogen may not be necessary.

Phosphorus is the nutrient which often constitutes a limiting factor in peat and gley soils, and on most sites the addition of phophorus has produced a marked response in tree growth. In the United Kingdom and Scandinavia phosphate fertilization in peat bog afforestation is a standard practice. Fertilizer is applied at the time of planting; ground rock phosphate or basic slag is used, particularly when application is by machines, but superphosphate or triple superphosphate is used when application is by hand. Combined phosphorus and potassium fertilizers containing 16.5% each of P and K are also used in peat bog afforestation.

On very acid soils, heavy liming is often beneficial; the lime improves the physical properties of the soil and reduces soil acidity, thus promoting nitrogen mobilization. Alkaline soils with a high sodium chloride content can, under some conditions, be improved by the addition of ground gypsum; i.e. by replacing the sodium by calcium.

## MINE TIPS AND SPOIL SITES

Industrial activities, especially those concerned with the mining and the metallurgical industries, often produce areas of waste land where unwanted material is dumped to form mine tips, slag heaps or slurry ponds. These areas of industrial waste land leave unsightly scars which come to be resented by the inhabitants of the area, and often pressure is brought on the authorities concerned to reclaim the areas or to screen them with a green cover of vegetation or tree plantations. Sometimes it is possible by afforestation to create parks of amenity value for neighbouring urban populations or to restore productivity to the affected areas.

In many man-made industrial waste lands, site factors inhibiting natural revegetation from seeds blown in from neighbouring unspoiled land are present. They are directly linked to the type of mining or industry concerned, which allows industrial waste lands to be classified into a number of categories, as described in the following sections.

### Types of Industrial Waste Lands

**Strip Mining Waste Lands**

In strip mining, topsoil and rock overburden are scraped away to expose the coal or mineralized strata required for industrial processing. After mining, the resulting waste land may consist of crater-like cavities alternating with dumps of material from the overburden which vary in texture from former topsoil to broken rock waste with little or no earth.

On hilly sites mining will usually have been worked on the contour, resulting in a series of rock terraces and steep scree banks where the overburden has been tipped downhill.

Where the dumped material contains 20 percent or more soil, revegetation by seeds and spores blown in from neighbouring unspoiled land may occur soon after mining operations cease, indicating a potential soil fertility suitable for direct afforestation. Elsewhere the exposed rock strata and dumps of rocky material and stones, often compacted by the passage of the heavy earth-moving machinery, must await the slow process of soil formation through exposure to the atmosphere and reshaping by wind and water erosion. Absence of humus and nitrogen is typical of most of these sites in the early stages.

Site preparation for tree planting consists ideally of reshaping the waste area with earth-moving machines, filling in cavities and levelling or smoothing down the dumps before finally covering the whole area with topsoil. Preferably the soil originally covering the land should be used, if this has been segregated in special dumps, or soil may be imported from elsewhere. Such work is very costly, but in some countries restoration of the site is an obligatory condition of the mining licence.

If reshaping is not possible, afforestation can be started on areas colonized by natural vegetation, while in the remaining still sterile areas, trees of hardy pioneer species can be planted in larger holes to which imported soil has been introduced. In areas such as brick fields, the derelict excavations are often filled with water, to provide artificial lakes for recreation, and tree planting for amenity is confined to the lake shore areas.

Colliery and Deep Mine Tips

Waste spoil from underground mining operations is usually brought to the surface and tipped in large heaps or flat-topped spoil banks. High tips and conical or table-mountain forms of spoil heaps usually have steeply sloping unstable sides, thus they are subject to land slip if the foot of the heap is undermined by a stream or by drainage water impounded or trapped in the complex configurations resulting when the spoil heaps encroach upon or block drainage runways. These tips consist of crushed and sometimes pulverized rock and are characterized by sudden changes in particle size depending on the source of material being tipped, but the material is very porous, permitting the easy penetration of air and rainwater and also of plant roots. The material, however, cannot be described as soil and will remain sterile until the rock particles are weathered and, in course of time, become colonized by soil forming organisms and eventually by pioneer vegetation.

Preparation of such sites for afforestation involves first of all stabilizing measures to minimize land slips and erosion. This may involve building walls at the foot of tips encroaching on natural water courses to prevent water eroding and undercutting the slope and, if necessary, canalizing the water courses in masonry chutes or concrete conduits. Ponds of trapped water within a complex of tips should be drained away if there is danger of collapse due to erosion in subsurface drainage channels. The flat tops of some spoil heaps can be re-soiled, but the slopes may have to be contour trenched or terraced and imported soil filled into planting holes.

Access roads should be constructed before afforestation and care taken to dispose of road drainage water in ways which minimize soil erosion and ravine formation in the relatively soft tip material.

For the first rotation it will generally be advisable to plant hardy pioneer bushes and trees capable of adapting to the severe limitations of the site, thereby creating better soil and microclimatic conditions. The second rotation of trees can be of greater economic value, and can sometimes be introduced by underplanting the pioneer crop.

## Mechanically Treated Waste Lands

In some industries the use of crushers, mills and washing plants produces finer grain particles in the process of separating the coal or metal ore from the waste. Many fine waste materials, for example, the losses in lignite strip mines, or the waste from bituminous coal preparation plants, can be suspended in water and pumped in pipelines to embanked basins or to slurry pits, where they settle, forming flat new areas. These flat fields of water-sedimented loess are very fertile unless rendered toxic to plant growth by the accumulation of noxious compounds from the rapid oxidation of sulphide particles at rates faster than the rate of leaching. In such cases, the land will remain sterile for long periods unless some form of flood irrigation with subsoil drains can be used to wash the salts out of the soil.

If fine material is tipped, the danger from land slips will be accentuated unless stabilizing techniques similar to those mentioned in the preceding section are employed.

## Chemically Treated Waste Lands

The huge group of chemically treated wastes can be classified into burned and unburned material. Burned material, for example the ash and slag from power stations, consists of oxides, silicates and sulphates of iron, aluminium, calcium, magnesium, potassium and sodium. As a result of their content of free bases, most of these ashes possess a high alkalinity and salt content, which may initially prevent plant growth. Leaching of the soluble salts and reaction with atmospheric carbon dioxide lessen their toxic effect in time, unless the waste contains boron or other elements highly toxic to plant life. Brick and clinker waste, broken glass and cement waste are further examples of burned waste, but these usually contain less soluble salts than the ashes referred to above.

Unburned chemically treated wastes are produced in metallurgical plants where the milled ore is "floated" in order to separate the stone from the metal. Such wastes are generally pumped out to sedimentation basins and to slurry ponds forming flat fields. The flotation agents used for different ores can impart strongly acid or alkaline reactions to the sedimented waste depending on the agent used, for example the cyanide flotation process used for extraction of copper and iron ores can be mentioned in contrast to the alkaline agents used in the gold mines of South Africa which give the waste a pH reaction as high as 11.0.

The afforestation of chemically treated waste dumps cannot usually be attempted until accumulation of noxious chemicals have been leached from the soil and the pH value raised or lowered to the range tolerable to plant life (pH 3.5 - 8.5). Natural leaching processes can be accelerated by soil washing methods, though this adds considerably to the cost.

## Other Forms of Waste Material

The disposal of domestic refuse, especially from large conurbations, has in the past produced large waste dumps consisting of both organic and inorganic materials. Generally speaking, land covered by domestic refuse tips forms favourable tree planting sites so long as they are free-draining. Where impeded drainage gives rise to anaerobic conditions the soil may become toxic through decomposition of organic matter and the liberation of hydrogen sulphide.

The dumping of waste products from synthetic chemical industries can give rise to a more intractible form of waste land. Synthetic material of organic origin can be destroyed by burning, but waste salts and inorganic compounds must be tipped or sunk in deep porous strata.

## The Choice of Establishment Techniques

Before attempting to initiate afforestation on industrial waste lands, the forester should make a detailed study of the limiting site factors. These will largely decide the scope and intensity of the preparatory work required, the choice of species which combine adaptability to raw soils with economic value, and the likely social or economic end results of the planting effort.

### Evaluation of the Site

The site should be examined to determine its actual or potential fertility. This involves an investigation of the materials in the waste to origin and size of particles, the topography of the tips, especially in connection with erosion and land slip hazards, and the presence of noxious salts or chemicals. Where natural vegetation has already colonized the waste area, a study of the component species may well indicate areas where soil conditions approximate those suitable for a forest crop, as well as give information helpful in the selection of the tree species to be used on different sub-sites or exposures. Those areas avoided by natural vegetation may indicate the presence of limiting site factors needing special treatment, and the pattern of colonization will certainly aid the work of mapping the various sub-divisions or sub-sites in the area.

### The Choice of Species

Except in those favourable cases where it has been feasible to cover the waste lands with a substantial layer of fertile topsoil, the trees selected for planting will normally be chosen from a limited list of species in each climatic range which have the capacity to survive in largely raw soils and to enrich the soils gradually by adding humus and nitrogen. The selection may well include a mixture of species, some destined simply to form an under-growth or even an herbaceous soil stabilizing cover. Extremes in the soil pH values or the presence of noxious salts may still further limit the range of choice. In all cases it would be wise to establish a series of trial plots to find out which species are best adapted to the site and which planting and fertilizer techniques give the best results. Experience from such trials may indicate the possibility of planting the selected tree crop directly or, where this is not feasible, show that some sort of nurse crop is needed to improve the site for tree planting at some later stage. The importation of good fertile soil, even if only enough to fill the planting holes, will almost always be needed in order to inoculate the land with soil forming organisms and mycorrhizal symbionts.

### Economic Considerations

The choice of treatment will be decided by cost, by the effectiveness of the establishment methods, by the possible future value of the tree crop and by the ultimate purpose or objectives of the reclamation.

Industrial waste land will rarely offer easy or inexpensive conditions for afforestation, but there are plenty of techniques available for the improvement of tree growing conditions. To recapitulate, some of those most commonly used in reclamation are:

1) Reshaping the contours in order to minimize erosion or to facilitate future management;

2) Covering toxic or infertile material with soil or waste of better quality;

3) Neutralising strong acid or alkaline spoils by the use of lime, sulphur, or waste of the opposite reaction;

4) Buffering toxic elements by the use of peat, humus, clay, or other material with a high exchange capacity. Water holding capacity and nutrient availability will be increased at the same time;

5) Leaching of salts, acids or alkalis by means of rainwater collected by ditches and basins or by irrigation, on heavy soils accompanied by artificial drainage;

6) Loosening the soil on compacted land or sulphide wastes by subsoiling to provide better aeration;

7) Fertilizing with organic or green manures or with compound fertilizers;

8) Stabilizing the surface of waste tips of very fine particles by agglutinating sprays or branch mulches and by constructing windbreaks where aerial erosion is a problem;

9) By watering or irrigating the plants if this is necessary, to get them well established after planting.

The costs of establishment may often be higher than the potential cash value of the tree crop would seem to justify, but it is also necessary to assess certain intangible benefits such as the improvement of amenities, the provision of recreation for densely populated industrial areas, or the prevention of site deterioration. Control of further site deterioration or degradation is often associated with protection against erosion, consequent siltation and flooding of fertile down-stream agricultural lands.

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# CHAPTER 5

# PROTECTION

All newly established plantations are liable to damage by weather conditions, by insect, fungal or viral pests, by fire, by wild and domestic animals and by man. The degree of risk from any of these causes will vary with the environmental conditions of each plantation and should be assessed during the planning stages, so that preventative measures can be taken or at least anticipated during establishment.

In theory remedial measures can be devised to guard against most forms of likely damage, except perhaps tornados or hail storms and other extreme weather phenomena for which insurance brokers use the term "Acts of God". Forests and plantations, because of the cover and shelter they provide, may sometimes suffer from indiscriminate acts of war, but for all predictable risks, the main problem facing the forester is one of assessing the cost/risk/benefit ratios. Total protection against all risks, or against one or more of the more probable risks, might well prove so costly that no final commercial benefit would result from the planting investment. In such cases a decision must be taken either to abandon the project or to compromise by accepting some degree of risk, thereby reducing the costs of protective measures to a more acceptable level. Not all risks can be readily forecast or assessed, and this is particularly the case where exotics are being planted in new environments where native insects or fungi may adapt to the new hosts. On the other hand, the probability of other types of damage can often be more realistically evaluated and the cost/effectiveness ratios of remedial or protective measures can be assessed.

Some of the main risks of damage and the measures available to secure protection are discussed under weather, insect or fungal pests, animals, including man, and fire protection as follows.

## WEATHER CONDITIONS

The frequency of damaging phenomena such as cyclones, tornados, hail storms, drying or salt-laden winds, severe frosts, heavy snowfall and avalanches are usually predictable, though foresters can do little to protect plantations against the damage caused by them, except by growing tree species known to be resistant or by siting the stands in sheltered localities. Some species are more windfirm than others, or are less prone to damage from crowns and branches breaking off in high winds. Other species are more tolerant of salt spray and can be used for planting in belts along exposed seaward flanks to give protection to other less tolerant species forming the main plantation. Thin barked species are more liable to that damage (and to subsequent attacks of insect or fungal pests) than others. In South Africa the planting of Pinus radiata and P. patula in many parts of the country has had to be abandoned on account of severe attacks of the fungus Diplodia pinea associated with hail damage. Pinus elliottii and P. palustris, which are largely resistant to Diplodia attack, are being planted instead. Frost can sometimes cause severe damage even to species known to be frost hardy in their native habitats. Late or unseasonal frosts occurring outside the dormancy period can result in severe setback to young trees by killing the new and tender growing shoot buds or tips. Remedies lie in selecting late shooting species or provenances; Picea sitchensis, for example, is generally more frost hardy than P. abies, and some species and provenances of eucalypts are more resistant to frost than others. Some protection may also be given to susceptible trees by planting them in mixed stands together with frost-resistant species. In regions of heavy snowfall, it is necessary to select species which are less susceptible to breakage under the weight of heavy snow.

## INSECT AND FUNGAL PESTS

Most insect and fungal pests are selective of the host species. In their native environment, trees whether in natural or man-made forests, normally attain a state of equilibrium with indigenous pests. When exotic trees are planted, those pests may be introduced and sometimes develop greatly enhanced virulence in the conditions of their new habitat. Well known examples of this are the chestnut blight (Endothia parasitica), a native of Asia, which caused havoc among chestnut plantations in Europe and North America, and the Dutch elm disease (Ceratocystis ulmi) which also spread to Europe and America from Asia, where most native Ulmus species are resistant to the disease. Sometimes exotic species may be attacked by local pests which adapt to new introductions. In New Zealand a native defoliating insect (Selidosema suavis) has become a serious pest in Pinus radiata plantations. The Cypress canker (Monochaetia unicornis) in East Africa is an unimportant disease on the native Juniperus procera, but has become, possibly by a change in strain, epidemic in the extensive plantations of introduced Cupressus macrocarpa. As a consequence this species is no longer planted and is being replaced by the more resistant C. lusitanica.

The risk of damage from pests and diseases is generally higher if the trees are physiologically weakened, for example from inefficient planting or site preparation, from being planted on unsuitable sites or in adverse climatic conditions or from neglect of weeding and tending operations. But even healthy trees are sometimes attacked. For many important fungal and viral tree diseases no control is yet available, and the best precaution is to plant species or varieties known to be resistant to the disease.

The main precautions to be taken, therefore, in guarding against possible future damage from pests and diseases are to see that the species selected for planting are suitable to the climatic and soil factors of the site, and to make surveys of indigenous pests, to ensure that none of these is among the known forms to which the selected species is susceptible. This is seldom easy, especially in view of the gaps in available knowledge on site requirements and disease susceptibilities of many of the more important exotic species; the more reason, therefore, for initiating carefully controlled experiments and plot plantations before developing large-scale afforestation work.

Care taken in the establishment and tending operations during the early years of a plantation, resulting in healthy vigorous young trees, makes a plantation more resistant to pests and diseases. However, if symptoms or evidence of attack appear, these should be promptly investigated and the cause identified. Various control measures are available: these may be silvicultural, chemical, biological or mechanical.

## Silvicultural Control

Silvicultural measures include well-timed and careful thinnings, mainly after the establishment phase has ended. These help to resist attacks by eliminating poor and suppressed stems, thereby maintaining the plantation in a thrifty and vigorous growing condition. In young plantations,the prompt removal and destruction of infested trees may be effective in preventing the spread of the attack to the rest of the plantation. Planting of mixed species can also be considered a silvicultural control method where the threat of infection is known to exist. The disadvantages of mixed planting within a compartment or plantation unit, giving rise to complications in later management, can be avoided by planting alternate blocks or wide belts with different species or genera, such as conifers and hardwoods, to form barriers to the spread of a disease from some initial point of infection.

## Chemical Control

Insect and fungal pests can also be checked by applications of an appropriate chemical insecticide or fungicide. These are usually available in liquid (or wettable powder) formulations, as dusts or as smokes. Spraying with hand-operated knapsack spray guns or portable mist-blowers is used to control attacks in very young plantations, but after canopy closure, aerial spraying and dusting or smoking is usually cheaper and more effective.

Dieldrin and aldrin have been successfully used against termite attack in tropical eucalypt plantations. A small dressing of insecticide is either mixed into the nursery potting soil or mixed with water as a suspension and watered on. Insecticides have also been effective when applied to the soil around the plants at the time of planting.

In South America leaf-cutting ants, usually of the genus *Atta* or *Acromyrmex* are the chief pests of forest plantations. These can be controlled prior to planting and during the establishment phase by fumigating the nests with methyl-bromide (sometimes mixed with chloropicrin to produce a detectable odor) or by treating the nests or ant trails with mirex or other chemicals. Treated baits which are carried underground into the nests by the ants are particularly effective.

*Dothistroma* on *Pinus radiata* in New Zealand has been kept under control by copper-based sprays (Gilmour and Noorderhaven, 1973); and a brown needle disease, probably *Cercospora pini-densiflorae*, seriously affecting *P. caribaea* seedlings in Malaysia was controlled by nursery applications of the fungicides benlate, topsin M, daconil or difolatan 4F (Ivory, 1975).

The insecticides and fungicides most commonly used are noted in tables 3 and 4.

## Biological Control

Biological control of insects has been used with success in certain cases, usually after the pest has grown to epidemic proportions. In southern and eastern Africa, for example, a Mymarid egg parasite imported from Australia has proved to be an effective agent of control against the Eucalyptus snout beetle, *Gonipterus scutellatus*, a major defoliator of *Eucalyptus* spp. (Browne, 1968).

## Mechanical Control

Mechanical control can be effected either by physically removing and destroying the pests or by eliminating an alternate host. Some fungal diseases, for example, have alternate hosts. The best known example is white pine blister rust (*Cronartium ribicola*) on *Pinus strobus* and other 5-needle pines, the alternate host being species of *Ribes*. The control method in such cases is to eliminate the alternate host plant by cutting or by using herbicides within the plantation area and for a zone (at least 3 kilometres wide) around the periphery.

In Tunisia the Eucalyptus longhorn beetle, <u>Phoracantha semipunctata</u> was brought under control by the use of trap trees. From ten to fifty trap trees per hectare are used, depending on the severity of infestation. The trap trees are cut and, after slicing the bark with a machete, they are leaned into the crowns of the remaining trees. After a few weeks, the trap trees are extracted and their bark, with beetles, is removed and burned. The wood can be utilized. Sexual attractants can also be used to draw the insects to the trap trees.

In the case of undesirable insects which pupate in the leaf litter or top soil, raking up the litter and burning helps to reduce the incidence of the attack. Pigs rooting in the litter in pine plantations have been found beneficial in South Africa. In South America, leaf-cutting ants are sometimes burned out by soaking their nests with kerosene and igniting. Chemical control is preferred, however.

Table 3: <u>Useful Insecticides</u>

| Pest | Chemical Control |
|---|---|
| Aphids | DDT, Demethon-methyl*, Diazinon, Dimethoate*, Malathion, Menazon*, Mevinphos*, Nicotine, Oxydemeton-methyl, Parathion, Phosphamidon*, Schradan*, BHC (or DDT with BHC), Endrin, Mecarbam. |
| Beetles | BHC, DDT, BHC with Thiram, Derris, Malathion. |
| Capsids | DNOC in Petroleum oil (only for hardwoods in dormant stage), BHC, DDT, Diazinon, Nicotine. |
| Caterpillars | DDT, Derris, Mevinphos*, DNOC in Petroleum oil, Lead arsenate, "Rhothane", Carbaryl, Endrin. |
| Leaf-cutting ants | Mirex, Aldrin, Dieldrin, Heptachlor, Chlordane, HCH, Lindane. |
| Leaf hoppers and miners | BHC, DDT, Malathion, Diazinon, Nicotine, Parathion. |
| Mites and red spiders | Demeton-methyl*, Oxydemeton-methyl*, Schradan*, Tetradifon, Azinphos-methyl, Chlorbenside, Chlorfenson, Dimethoate*, Ethion, "Kelthane", Malathion, Phosphamidon*. |
| Sawflies | BHC, BHC with DDT, Endrin, Phosphamidon*. |
| Soil pests (termites, chafer-grubs, cut-worms, etc.) | Aldrin, Dieldrin, BHC, DDT, Lead arsenate. |
| Weevils | DDT, Aldrin, Dieldrin, Rhothane. |

* These are systemic insecticides (that is, absorbed and distributed in the plant sap).

Table 4: Useful Fungicides

| Diseases | Chemical Control |
|---|---|
| Damping off fungi in nurseries, needle blight (*Scirrhiza acicola*), blister rusts (*Cronartium comptoniae*). | Bordeaux spray, Captan Orthicide |
| Southern cone rust (*Cronartium strobolinum*). | Perbam |
| Cedar blight (*Phomopsis juniperovora*). | Phenyl-mercuri-triethanol-ammonium-lactate |
| Mildews, scab, *Dothichiza* sp. | Lime sulphur |
| Needle blight (*Dothistroma pini*), needle cast (*Lophodermium pinastri*). | Copper fungicides |
| Root fungi (*Fomes annosus*, *Armillaria mellea*) | Creosote (painted on cut stumps) |

## ANIMAL DAMAGE

### Damage by Wild Animals

Damage to forests by wild animals mainly takes the form of tree browsing or of barking. There are three main orders of wild animals responsible for damage:

- rodents (rats, mice, moles, squirrels, chipmunks, and porcupines);
- lagomophs (hares and rabbits);
- artiodactyls (deer, antelopes, pigs and buffaloes).

In specific geographical regions, serious damage is also caused by proboscoides (elephants in Africa and southern Asia), marsupials (oppossums in Australasia and the Americas) and primates (monkeys in Africa, Asia and South America). Seed-eating birds are also a frequent cause of difficulty, particularly where forests are established by direct seeding.

The principal methods of controlling wild animal damage are by use of (1) fences, hedges and ditches; (2) poison baits; or (3) by shooting and trapping.

#### Fences, Hedges and Ditches

The construction of barriers, such as post and wire fences or impenetrable live hedges (thorn bushes, cactus, etc.) are the most effective means of preventing the ingress of most wild animals, except the climbing types, the very small ones (rats and voles, etc.) and the very large animals (elephants, buffaloes).

Fencing is easy to erect at the time of establishment but is generally expensive. Where alternative means of protection are not feasible, the cost of fencing has to be accepted.

The type of fencing used varies with the type of animal to be excluded and the materials available. The standard fence for deer is 2 m in height, made of six strands of barbed wire strained on angle-iron or wooden posts at intervals of 3 to 4 m. In Europe, a long-lasting deer fence using metal posts is expensive, but fences using wire mesh and creosoted wooden posts cost much less. Where rabbits and hares are the main source of trouble, fine meshed (107 x 3 cm) wire netting is necessary along the lower part of the fence. In the U.K., it is also standard practice to bury the bottom (15 cm) of netting in the ground to prevent rabbits burrowing under the fence. Electric fencing has been used to exclude wild animals and domestic stock, but in general has not proved satisfactory. In very dry climates, they are ineffective unless fitted with an earth return wire.

Post and rail fences are sometimes used where wire is too costly or too difficult to obtain and where light poles are plentiful. In Kenya, a form of post and log fence has proved effective against most game for taungya plantations. It consists of pairs of posts 1 m apart at 2 m intervals with the interstices filled with logs or wood cleared from the planted area. In the African Sahelian zone, fences are sometimes constructed as staked barriers of thorny or spiny branches.

For the exclusion of elephants and other species of big game, moats (2 by 1.5 m ditches covered with brushwood) have been found to provide a most effective barrier in Kenya.

Hedges or barriers of closely planted bushes or trees, often of spine-bearing species, planted round the periphery are used in many countries to exclude game or, more often, domestic grazing animals. In Kenya, trial plantings of eucalypts spaced 1 m apart around conifer plantations are reported as having satisfactorily excluded very big game.

Hedges have many limitations in their usefulness:

1) They must be established several years ahead of the planting work and this is often inconvenient or not possible;
2) They need frequent tending, trimming and shaping to maintain their effectiveness;
3) They are not effective against small animals;
4) They are subject to damage by browsing, bark stripping and fire;
5) They take up more space than fences and
6) They hinder transport.

Poison Baits

Smaller mammals such as rodents and lagomorphs are mainly controlled by the use of poison, distributed either in bait or applied directly to ground vegetation or tree seeds. Most poisonous chemicals are of the "contact" variety, which are effective only as long as they remain on the surface of the trees or seeds, but research is currently being undertaken into the use of systemic poisons which are absorbed and translocated by the plant and provide protection for considerably longer periods.

Strychnine, zinc phosphide, sodium arsenite, warfarin, "1080" and thallous sulphate are examples of the many different poisons distributed in bait. In Australia a general method used for controlling rabbits is the distribution from the air of chopped carrots treated with "1080".

Endrin/aldrin emulsions and toxaphene (chlorinated camphene) have been sprayed on vegetation or young trees as a repellent.

Various poisons have been applied to tree seeds to reduce damage from rodents and birds. Endrin, a non-phytotoxic formulation containing thiram (tetra-methyl-thiuram-disulphide) has been used most commonly especially with coniferous seeds. Endrin has recently found a wider application on tree seed in sub-lethal doses as a repellent.

Colonial animals which live in burrows can be controlled by fumigation or gassing with chloropicrin, phosphine, carbon monoxide or cyanide. A new fumigating, which is being tried extensively in Victoria and Western Australia, consists of carbon monoxide combined with a foaming agent, which is forced into the warren killing the rabbits and coating the burrows with a residual repellent slime.

The main limitations affecting the use of chemical poisons are their toxicity to the people handling them and to non-offending animals and the prohibitions relating to their use imposed by law in many countries.

Shooting and Trapping

Shooting and trapping is also used to control wild animals, often in combination with fencing and poisons. Where the wild animals have value as food or as trophies, control by hunting can often be organised through volunteer hunters without cost (sometimes even with financial gain) to the plantation project.

## Trespass by Domestic Animals

In some countries grazing or browsing by flocks of sheep and goats, herds of cattle and more rarely of equines can constitute a major menace to young plantations.

Hedges and fences are commonly used to prevent trespass of domestic animals. In other circumstances, particularly where fencing costs are prohibitively high, trespass can be controlled by guards, and by taking legal action against the owners of straying animals. The impoundment and confiscation of such animals may occasionally prove an effective deterrent.

In many regions, especially in dry areas, free-range grazing by goats is traditional in degraded, eroding grazing lands. Extensive enclosures for forestry can mean the imposition of drastic changes in the habits and economies of the communities affected. In such circumstances it would be unwise to commence afforestation unless alternative means of livelihood, compensating the communities for restrictions in their traditional use of the land, had been provided beforehand. This generally implies the initiation of integrated community development schemes including improved agriculture and husbandry, better communications, schools and medical welfare, increased opportunities for employment by the development of rural industries, including afforestation and rural forest industries. In some cases, such development may involve providing inducements for localised emigration to new industrial centres, as occurred in southern Yugoslavia following the outlawing of all free-range goat grazing in the nineteen fifties.

## Trespass by Man

This can take many forms - encroachment cultivation, the diversion of water sources, the taking of wood and other forms of forest produce, unlawful hunting and fishing and other recreative uses of a forest. In general, the risk of damage by human trespass is not serious in the case of newly-established plantations except inasmuch as it increases the fire hazard. Where such forms of trespass constitute a hazard or are likely to develop subsequently as a source of trouble, it is part of good planning to make allowance for such community needs from the beginning of the plantation work. This may mean reserving certain areas of the plantation for the production of fuelwood, poles and other produce in demand by the local communities, by providing authorized hunting and fishing facilities, or by channelling people seeking recreation to specifically reserved forest amenity areas, provided with picnic sites, camping grounds and forest accommodation.

# FIRE PROTECTION

## The Fire Hazard

Damage by fire imposes a serious threat to plantations in most countries. The fire hazard increases, of course, in the dryer climatic regions, but even in relatively moist or high rainfall areas, there are often warm and dry spells when the fire risk is high. In many parts of the world, annual or periodic burning of vegetation is common practice, and establishing plantations in such areas requires that fire-risk should be a major consideration from the early stages of development.

Fires may originate from natural causes such as lightning, but most occur as a result of the activities of man. Plantation fires may start from camp or picnic fires, from fires spreading from farmland on the perimeter of the forest, from the activities of hunters or from burning by sheperds or herdsmen to improve grazing. There have even been recorded cases of deliberate firing to create employment in suppression and replanting or to show disapproval of forest policies. As forest contractors are also often careless in their attitude to fire, it would be advisable to include some fire protection requirements in contract agreements. It is not possible to prevent a climatic build up of high fire hazard conditions, but much can be done to minimize the risk of fire by public education, by involving local people in forestry and by persuing policies sympathetic to the political, social and economic needs of the community.

Where planted crops are either not weeded or are partially weeded, they are particularly vulnerable to fire during the establishment phase. Where plantations are clean weeded, however, there is no fire risk. By cultivating the soil there is no combustible material at ground level and the entire planted area including individual trees are protected. Once a plantation crop closes canopy, if the canopy is sufficiently dense to exclude grass and other weeds, then the risk of fire remains low. If, however, the plantation crop is light crowned, allowing a fairly dense ground cover of weeds, then the fire hazard is high.

The main principle in protecting plantations against fire is that where there is insufficient combustible material to allow a ground fire to develop there is little or no fire risk. Dangerous and damaging plantation fires can only develop when fire can occur at ground level.

## Fire Prevention and Hazard Reduction

The layout of a plantation is influenced by a number of factors already noted but fire control is one of the main considerations, which not only influences road and firebreak alignment but also the dimensions of compartments and blocks, amongst other items. A plantation requires both a "fire plan" and a fire control section. One of the primary requirements of such a plan would be to provide training in control and fire-fighting. A trained fire control section would be responsible for controlled burning, maintenance of firebreaks, assessment of fire hazard, maintenance of fire towers, fire reporting and initial fire suppression. Fire may start outside the plantation and carry in or may start inside and spread. Consequently fire control operations should be designed to prevent fires from both these sources.

## Firebreaks

The purpose of a firebreak is to provide access through the plantations and to provide a fuel-free barrier to fire. Firebreaks are generally oriented at right angles to the direction of the prevailing wind during the dry season. A road in itself may constitute a firebreak. A road may be supplemented by a narrow ploughed strip to form a composite firebreak. Firebreaks maintained by ploughing are sometimes ineffective if heavy grass cover is only partially removed during cultivation, and of course such cultivation adds to costs. Wide, cultivated firebreaks give every appearance of effectiveness, but can seldom be wide enough to prevent spot fires crossing from a high intensity fire. In addition to being costly to establish and maintain, they channel wind flow along the break and cause turbulence at the plantation edges.

Green firebreaks planted to suitable, usually evergreen species are a further possibility. The main requirement of a green firebreak is complete canopy closure and a clean forest floor maintained free of litter by periodic burning. When controlled burning is practised, green firebreaks become largely redundant as they receive the same treatment as the plantation.

With the limitations of the various types of firebreaks, the trend is towards an intensive internal network of narrow clear roads (at least 7 m of right-of-way) which serve as access and as firebreaks within blocks. At the same time, perimeter road/firebreaks are maintained, where there is a risk of fire from outside the plantation. To prevent fire entering a plantation from the surrounding areas, controlled boundary burning is often practised.

Although the tendency is toward narrow firebreaks, wide breaks are still used. In Pinus patula plantations on the Viphya Plateau in Malawi, firebreaks about 200 m wide are preferred. Where possible, these are sited to take advantage of natural terrain features such as rocky ridge outcrops. The firebreaks are burned annually to reduce fuel buildup; in addition a strip about 2 m wide is cultivated around the entire plantation perimeter to guard against the entry of low ground fires. (Courtesy D.A. Harcharik)

## Control Burning

Control burning is effected within the plantation in such a way as to cause no damage to the standing crop. It is, therefore, restricted to thick barked species and is seldom possible until the tree crowns are well above reach of the ground fire (i.e. after canopy closure). The timing of the first control burn in a young plantation is critical; for pines a mean height of between 8 to 11 m covers a range of likely suitable conditions, but this will vary with local conditions.

Where the fuel layer is heavy, burning should not aim at complete removal in one operation, as the conditions suited to a single burn could cause too intense a fire with inevitable damage to the trees. Heavy fuels can, however, be removed by several successive burns over the same area - removing a proportion of the fuel bed on each occasion.

Control burning is carried out under accurately defined weather conditions which should allow a prescribed pattern of fire behaviour to be achieved. It is best done late in the wet season, or early in the dry season, and at night, or at least after the hottest part of the day. As experience is accumulated it should be possible, for a given set of conditions, to estimate a period during which control burning will be effective.

The following general prescriptions are valid for most conditions: (Cheyney, 1971):

1) Conduct test fires to determine first the rate of spread of fire and second at what time fires might be self-extinguishing; these should be carried out in advance of the main burning operations.

2) If the forward spread of burning exceeds 60 cm per minute, burning should not be carried out.

3) Burning should only take place when wind conditions are calm or less than 8 km/hr.

4) There should be no burning if the relative humidity drops below 35% during the day.

5) Burning should commence in the afternoon or later when the relative humidity rises above 50%.

6) If tall grass is present in the plantation, burning should occur before these annual grasses have become fully dried.

## Fire Detection, Assessment and Supression

### Fire Detection

A sound fire detection system is usually based on fire towers. These towers should be sited to give maximum coverage of the plantation and environs and should allow ready triangulation so that accurate cross bearings can be recorded. Each tower should be equipped with an alidade, binoculars and a radio/telephone. The system should be established early in the plantation development.

### Fire Danger Assessment

Where there is a high fire hazard, the setting up of a fire danger rating system is recommended. Such a system which relates the four major meteorological factors affecting fire behaviour - temperature, relative humidity, wind speed and long and short term drought effects - may be readily calculated for most conditions.

### Fire Supression Techniques

The first essential in fire fighting is that there should be adequate transport to carry personnel to the site of fires as quickly as possible. If dealt with quickly, many fires can be readily extinguished by hand. A suitable range of equipment for a gang is:

- knapsack sprayers
- shovels - light, strong pointed
- axes (preferably 4 lb)
- machettes
- hoes (long handled with large blades)
- electric torches (for night operations)
- drinking water supplies
- first aid kits

Other items are the rake/hoe or McLeod Tool from Australia and back firing drip torches.

There is a considerable range of mechanised equipment for fire control - pumps, tankers and tractor units - which may be required under certain conditions. For effective use of much of the pumping equipment, there have to be suitable water supplies within easy range of the plantation area. Where water supplies are inadequate or too distant, recourse has to be made using fire fighting methods not requiring large volumes of water.

No two fires are likely to behave in the same way, but the following are general fire fighting techniques which might be employed in particular situations:

1) The first point of attack should be the head of the fire, followed by the windward flank.

2) Firelines parallel to the edge of the fire may be formed by:

   a) raking or hoeing to mineral soil and;
   b) by pushing material directly into the fire.

3) Back burning can be very effective but requires experienced crews. It should only be attempted from less than 100 m directly in front of the head fire.

4) Where water is scarce, it must be used efficiently; it is of particular importance in mopping-up.

5) Mop-up is the extinguishing of all burning and smouldering material within 20 m inside the fire control line. It is essential to continue mop-up and patrol until a fire is completely extinguished. Many apparently dead fires have restarted after being abandoned too soon.

It is essential to train staff and labour in fire fighting techniques. Training exercises should be held periodically, but too frequent training may reduce rather than increase interest and efficiency.

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# CHAPTER 6

# PLANTATION PLANNING

## INTRODUCTION

Planning can be done at several different levels. A simple example of the type of objective to be achieved at different levels of planning might be:

| Level | Example |
|---|---|
| 1. National forest policy or national forest objective | Make the country self-sufficient in wood by 2010 A.D. |
| 2. National quantitative forestry target | Produce X million $m^3$ of pulpwood annually in 2010 A.D. and an additional 5% annually thereafter. |
| 3. Project aim | Plant 2 000 ha of *Pinus patula* and 500 ha of *Eucalyptus grandis* annually in district A, for production of Y $m^3$ of long fibre and Z $m^3$ of short fibre pulp on rotations of 20 and 10 years respectively. |
| 4. Operational planning | Arrange beforehand how and when to obtain seed, prepare nurseries, carry out site preparation etc., in order to achieve the project aim as efficiently as possible. |
| 5. Execution or management | Convert operational plans into effective action. |

A previous publication (FAO, 1974) reviewed the principal features of development planning and explored how to identify the appropriate role of the forestry sector in national planning, how to define this in terms of sectoral objectives, how to translate these into quantitative goals and targets and how to identify and appraise projects within this framework. It did not cover operational planning - the balancing of work and resources in the short term and the completion of programmes of work within a timetable. Another document (Fraser, 1973), dealing with the planning of man-made forests, included a chapter on operational planning, but was mainly concerned with the phases of project specification, collection of data and project appraisal.

The present chapter is concerned solely with the operational planning of forest plantations - plantation management planning. This type of planning assumes the existence of clear directives which give little freedom of choice to the project manager as to what he does but some degree of freedom as to how he does it.

Although the scope of the chapter is deliberately limited to plantation management planning, it is necessary to stress the close relationship between the different levels or phases of planning. The methods worked out to achieve an objective at one level of planning often become the objective at the next lower level. Later experience will bring about an interaction between several planning levels. For example, experience gained in executing an operational plan may indicate how it should be improved, while project aims may be modified periodically to conform with changing national needs. As has been often stated, planning is an iterative process.

## PLANTATION MANAGEMENT PLANNING

Project operational planning provides a programme of action designed to fulfil the aims of the project. It prescribes what work will be done, where, how and within what timescale. Because of the long-term nature of forestry, it is essential that the outcome of planning forest plantations be expressed in the form of a written plantation management plan.

The manager of a forest plantation project is likely to be concerned with three levels of project planning:

1. A skeleton plan for long-term management of the project, which may cover a full rotation or more. Prepared during the phase of project identification/appraisal, it provides a framework in which the project manager is expected to prepare a more detailed management plan during the phase of operational planning.

2. The plantation management plan, covering a medium-term period and providing background information and management prescriptions.

3. An annual programme of work, indicating the work to be done, the resources needed to do it, and when it is to be done. This can usually be prepared on standard forms, with a monthly or weekly breakdown.

## COLLECTION OF DATA FOR THE PLANTATION MANAGEMENT PLAN

The collection of relevant data is fundamental to all phases of planning, and the quantity and detail of additional data required in the operational phase will depend to a great extent on the quality of data collected in the previous phases. In some cases, where the project identification and appraisal phases have been both expeditious and efficient, very little additional data may be necessary. The data required for a plantation management plan include resource, operational and institutional data, for use in both the descriptive and the prescriptive parts of the plan. Much of the technical and cost data will be derived from past plantation work, from pilot plantations or from trials. Operational data will be derived from records of past work either in the project area or from comparable conditions outside. Where adequate data have not already been compiled, surveys may be necessary. Very often data such as costs are not readily available and it is necessary to use estimates, while clearly stressing the need to make good the deficiencies by subsequent collection of the necessary data.

## Resources Data

The main resources to be considered are land, planting stock, materials and equipment, human and financial resources. The required information on these is availability, productivity and cost.

### Land Resources

The first essential is sufficient plantable land to accommodate the project planting programme; indeed, excess land is desirable to allow for unforeseen problems and possible future expansion. Where tribal or other legal rights affect the long-term use or availability of land, such matters require determination and clarification before further planning is undertaken.

In the early stages of development it is not possible to assign site quality classes to soil types, but a simple plantability classification can indicate the better areas for planting. The assessment of plantability requires a soil survey and the preparation of maps showing soil types, forest capability and vegetation types. At the same time as the vegetation is recorded the tree cover is sampled for basal area to give a measure of tree density, a major factor in land clearing.

Established growth trials of plantation species should be available to indicate the productivity for the range of plantable sites. There is some merit in planning to plant the better sites first while research and growth trials produce further data on secondary or marginal sites. Where forest reserve land is available, there are no direct costs for the resources but, where land is acquired by purchase or compensation, such costs are recorded and debited. The annual requirements for planting land should be allocated on a map of plantable land.

### Planting Stock Resources

The primary requirement is an adequate and sustained supply of seed of the selected species and provenances. Selection of species is a major subject but it is assumed that species and provenance trials will have been extensively evaluated prior to the preparation of the plantation management plan. Seed supplies often prove serious constraints on the proposed rate of development. Sources of supply and storage facilities should be precisely determined. If importation represents a risk, then local seed production and methods of expediting this must be given priority. Availability of seed must necessarily have some influence on the planting rate of species previously selected for silvicultural and utilisation reasons. A high standard of nursery technique is necessary if the highest possible number of vigorous, plantable plants is to be obtained from a given quantity of seed. When purchasing seed it is the cost per plantable seedling and not the cost per unit weight which is of consequence. The annual requirements of seed and seedlings and the cost should be readily calculated from the data collected.

### Material and Equipment Resources

These fall into three main categories: those required for the administrative organisation, for operational activities or for maintenance and support. Administrative requirements include offices and buildings and minor items such as office equipment and stationery which are common to any enterprise. Operational materials and equipment are specific to plantation development; a general outline of such equipment and material is given in Appendix C. Maintenance and support items include workshop equipment, transport and spare parts. The critical factors with reference to stores are to select those items suited to the particular work and scale of the project and to ensure that such equipment or materials, together with spares, are available on site when required. This necessitates the provision of ample storage.

Equipment offers a considerable range of options, and the types suited to the work should have been determined at the appraisal stage.

The productivity of equipment is critical to the efficiency of a project. Evaluations of the output of equipment may be of little value unless allowance is made for variables and the basis of measurement is stated. Good productivity requires as full an annual or seasonal utilization of equipment as possible. Scale of operation and operational data are required before most stores or equipment requirements can be set out. When the types of equipment and materials have been finalized, an assessment of the total requirements by years can be drawn up for the full period of the project.

The purchase or capital cost of all project materials and equipment is required for estimates, budgets and costing the total project requirements. For comparative evaluations, the planner requires the hourly operating cost of the equipment, from which unit productivity costs can be calculated. In the initial stages of a project this may have to be estimated.

## Human Resources

Man is the most important resource in the project, and due consideration of his abilities and reactions is required in deciding on possible courses of action. The possible sources of labour and staff require study, as they determine the need for additional investment in transport or housing. Employees benefit from a plantation project not only in cash wages, but also from training, improved housing and security. Experience in Swaziland points out the benefits of employees living in mixed communities rather than exclusive project settlements of villages (Hastie and Mackenzie, 1967). A plantation project involves many skills and requires managers, supervisors, mechanics, machine operators, administrative and clerical staff, medical staff and both skilled and casual labour. In particular, if a project is to be selectively mechanized, then provision for the employment of skilled mechanics and operators is mandatory, and training will often be necessary. The availability and capability of the management and supervision require careful assessment.

The cost of human resources is the sum of salary or wages, social and fringe benefits, leave and sick time. The manpower requirements of the project should be set out for staff by years, categories and responsibility. Labour is similarly recorded, but operations replace responsibility. To estimate the annual labour force, a calendar of operations and labour inputs not only gives the necessary data but also allows fluctuations in requirements to be smoothed out to provide more regular employment. Information on the productivity and unit costs of labour will be extracted from operational data.

## Financial Resources

Generally some indication of the finance available for the full project, or a phase of the project, will have been given at the outline or appraisal stage. The plantation management plan should be tailored to fit this financial framework, but where finance proves to be a critical constraint the case for an additional allocation should be made. The total costs of the land, planting stock, material and human resources, plus contingency, represent the allocation required, and the range of these figures should be set out as annual requirements for the entire project period.

It is important that the financial authority should understand that a plantation is a dynamic enterprise not readily accommodated in the fiscal year concept. Plantation operations such as land clearing, nursery and weeding are interrelated in time in that one year's programme can affect both the previous year's and next year's programme. This means that delays in funding or erratic allocations will not only affect the year of occurrence, but also past and future investments. Two possibilities of overcoming this problem are either to consider the project as a capital investment until normality is achieved, or to make funds available on three or five yearly allocations. The ready availability of funds, however, does not preclude carefully planning their investment.

## Operational Data

The data to be recorded in this section for all plantation operations are:

1) Unit of measurement - eg. ha, km or '000 plants;
2) Input - man-days, machine operating time, materials;
3) Output - units per hr, per day, etc. and
4) Cost - of each resource per unit.

These data allow a ready estimation of the productivity of men and machines and of the total requirements of such resources for particular project operations. The collection of operational data is critical and fundamental to the planning process. The information must be the best known and may be extracted from costing records where available but, if it is lacking, sampling work outputs may be necessary to provide indicative data. Operational data provide a basis for appraisal, for estimating resource requirements, and budgeting; consequently it is vital that the source and reliability of all such data are recorded. A project or plan is only as realistic and workable as the data used in its design. The combination of resource and operational data into arithmetical calculations leads directly to management prescriptions. A simple example for seed collection and handling is shown in Appendix D.

## Institutional Data

Institutional factors to be noted are mainly of a political nature, but include the project legal framework and the commitment of the supervising agency in other fields, such as training. Other factors on which information should be collected are the interrelationship of the local community and the project, facilities for multiple land use and information on plantation research in progress but insufficiently advanced for appraisal.

The legal framework should provide appropriate and effective legislation and regulations and the means to enforce them. It should also be determined that an adequate management and administrative structure exists or will be available to run and service the project.

# THE PLANTATION MANAGEMENT PLAN

## Purpose and Content

The plantation management plan forms the basis for management action and forecasts and records in some detail what the plantation manager has to achieve over a period. In the case of a 30 year rotation, the initial plantation management plan might cover some five years or possibly less. The remainder of the project life will be covered by similar periodic plans. This periodic planning allows a flexible approach to project management and, the more stable and well defined the project environment, the longer the plan periods can be. The presentation of the plan should be kept as simple as possible since effective management requires some flexibility in the planned work programme. For complex projects or problem areas, network analysis may prove a useful management tool in solving problems or bottlenecks. An introduction to network analysis is given in Appendix E.

There is no set form for a plantation management plan, this must vary with local conditions and requirements, but the three essential parts in any plan may be considered as Part I, Directive; Part II, Descriptive and Part III, Prescriptive.

Part I, Directive, consists of the instructions received by the project manager from higher authority as to what the project is to accomplish. Part I cannot be altered by the project manager, but only by the authority which issued the original directive.

Part II, Descriptive, provides information on the local environment, past history, existing facilities in staff, roads, buildings etc., which is the essential basis for management prescriptions.

Part III, Prescriptive, prescribes how, when and with what resources future operations are to be carried out in order to accomplish the purposes of the project laid down in Part I. Normally the project manager has discretion to alter these prescriptions in the light of experience, in which case he must inform higher authority and amend the written plan. Part III will require more frequent revision than Parts I and II. A concise outline of the headings which could be included in a plantation management plan is as follows.

### Outline Plantation Management Plan

| | |
|---|---|
| Part I (Directive) | **Policy and Objectives**<br>Policy<br>Objectives |
| Part II (Descriptive) | **Basic Information**<br>The project environment<br>Land availability and suitability<br>Institutional framework<br>Past management and history of the project |
| Part III (Prescriptive) | **Present State and Future Management**<br>Allocation of working circles<br>Detailed prescriptions of activities<br>- Plantation operations<br>- Other works<br>- Provision of resources<br>- Finance: expenditure budget and revenue<br>- Costings, records and control<br>- Map records |

### The Plantation Management Plan, Part I

Part I should be received by the project manager as a directive from higher authority. He is responsible for ensuring it is recorded in the written management plan. The objectives of the project should be stated with complete clarity; if they are not, the project manager should seek clarification before starting his own operational planning.

### The Plantation Management Plan, Part II

Part II sets out the information basic to the project. It should include:

1) A description of the project environment including the location of the project and information on geology, climate, hydrology and natural vegetation;

2) The land availability and suitability, described in the text, and supported by tabular statements and maps. Where site classes are known these should be defined and delineated;

3) The institutional framework of the project including its legal status, together with its organisational structure;

4) The past management and history of the project, including a brief description of project development and any past management information or data relevant to project development. This section should note any salient features on which the planned project programme is based. This section of the plan will be brought up to date at the end of each plan period by adding what has been accomplished in that period.

## The Plantation Management Plan, Part III

Part III is the most important part of the plan, it contains a forecast of those operations that are to be implemented by management. Where necessary, the project work may be divided on the basis of different species or different silvicultural systems, by the allocation of working circles. Plantation programmes of work are set out by years for each working circle for the specified plan period (see, for example, Appendix F). The plans for each year can readily be extracted and shown as "annual programmes of work" for all project activities. These annual programmes may then be further broken down by time and area to serve as action plans for assistant managers and supervisors. See also page 146.

The detailed prescriptions of activities generally record the present state and prescribe what future work or action is required under the following main headings:

1) Plantation operations and other works
2) Provision of resources
3) Expenditure budget and revenue
4) Costs, records and control
5) Map records

### Plantation Operations and Other Works

This section covers the main plantation and building operations. The state at the commencement of the plan is recorded and detailed prescriptions set out the method of operating and the quantity and timing of forecasted inputs and outputs for each operation.

The main relevant operations are:

**Plantation operations**

Allocation of land
Surveys
Establishment of nurseries
Raising plantation stock
Land clearing and preparation
Plantation layout and construction of access
Planting
Beating up
Fertilizing
Weeding
Brashing/Pruning
Thinning
Final felling
Fire protection
Road maintenance

**Other Works**

Building and services
Maintenance of buildings and services
Maintenance of transport and equipment

The present state and prescribed work for each operation is very often set out in tabular form. The prescription is usually supported by details of the estimated inputs of labour, material and equipment for the main operations. The prescriptions concentrate on what will be done, where and when, and the method may be covered by referring to a handbook or memoranda of instructions, or may be described in detail if such references are not available.

The forecast of planting is affected by land availability, species growth and yields, rotation and markets, and by availability of other resources. In the case of large afforestation schemes it would be convenient to divide the available areas into a number of even-sized planting blocks corresponding to the number of years in the rotation. In practice, it is more common to commence planting at a reduced scale and, as experience and expertise are developed, to increase the rate. On the other hand, where the capacity exists, initial planting may be at a rapid rate, which later will increase the options in choice of rotation length, and in an era of inflation reduces total establishment costs.

Plantation layout includes the design and delineation of compartments, blocks, main and secondary roads, rides and fire traces. This constitutes a major aspect of planning which requires careful study for specific projects. The initial layout should be adapted to the pattern of plantable soils, topography and natural features, but the design will also be influenced by fire protection requirements and anticipated methods of logging and extraction. Some projects have exceptionally large compartments of over 200 ha, but a more general range is between 20 and 40 ha. Blocks may be of any size but are generally confined to one year's planting.

Roading densities vary but are usually of the order of 1 to 4 km per square kilometre, according to terrain. Only a small proportion of the roading needs to be high standard; most can be low class roads. Initially, many of the lower class roads are either unsurfaced or lightly metalled; upgrading of these roads for logging occurs closer to the time of harvesting. Main plantation roads are generally constructed as all weather routes to allow access for planting, maintenance and fire suppression; but they are not constructed to standards suitable for logging. Some guidelines on the establishment of plantation roads are given in Appendix B.

The major protection factors are fire prevention and suppression; the plan will prescribe such firebreaks, boundary burning, controlled burning and other measures as are considered necessary. Where there is a high fire hazard the provision of radios or telephones linked with fire lookouts will be required, together with the establishment of a fire suppression organization. The risk of damage from biotic causes should have been carefully evaluated during the collection of data phase, and the selection of plantation species and techniques should be designed to minimize any such risks.

### Provision of Resources

A general indication of resource requirements for the plan period will have been set out in the previous section on plantation operations and other works. The prescriptions in this section will set out which resources should be acquired by specific dates. The main resource requirements are:

#### Personnel

- Allocation of staff and definition of responsibilities
- Allocation of labour and calendar of labour requirements
- Training of staff and operations

#### Equipment

- Machinery transport and equipment
- Building materials
- Project materials and seed
- Essential spares

The development of plantations often requires the enlargement of the existing forest service and, in some cases, the creation of a new management section to execute the planned project. The plan should detail by years the personnel required to implement the programme, such personnel to include professional forest managers, foresters, technical assistants and various supervisor grades. The responsibility of the manager and his supporting staff should be defined. The allocation of labour comprises a summary of the prescribed labour requirements to implement the component operations and is set out as a calendar of operations, a sample of which is given in Appendix G. The preparation of these calendars allows the labour requirements to be smoothed out both within a year and over the plan period, to avoid erratic dismissals and ensure continuity of employment for the major labour force.

As the plantation area develops, there will be a steady demand for additional staff and it will be necessary to plan the provision of facilities for the various grades of staff to be trained in plantation management and operations. As labour will be required to develop skills in silvicultural work, nursery work and, in some cases, in mechanization or irrigation, it will be essential to provide adequate training.

The prescriptions for equipment and material set out what items are required by what date if operations are to be completed as planned. A monthly calendar of machine requirements, similar to that for labour in Appendix G, will be required. The requirements may be estimated on gross known requirements such as one tractor per x ha, or amount of fertilizer per 100 ha or per 1 000 plants in the nursery.

A breakdown of material and equipment inputs will have been recorded under individual plantation operations and other works, and this can either be collated to give an estimate of requirements or to cross-check gross estimates. It may be necessary to seek specialist advice for the specifications of such items as machinery, transport and building materials. Where delays in obtaining certain items can be foreseen, advance ordering is necessary, and for many materials and spares the setting up of a strategic reserve in storage is essential. Late arrival of stores frequently acts as a bottleneck to implementation; ordering of equipment, therefore, warrants careful planning and attention to detail so that it is done both timely and correctly.

Appendix C gives an outline check list of equipment and materials which could be required for plantation development.

Finance: Expenditure Budget and Revenue

The plan generally includes an expenditure budget. This budget represents the estimated cost of all the resources required to achieve the prescribed programme. It is usually drawn up by years and is set out under such functional headings as:

| | |
|---|---|
| Land clearing and preparation | Building maintenance |
| Nurseries | Equipment and materials |
| Plantation operations | Equipment maintenance |
| Capital cost of land & building | Administration and staff |

The approved budget is the authority for the allocation of funds to the project. If annual financial allocation is prescribed, then extraction of the annual data from the budget can serve as yearly estimate submissions. When release of funds is requested during the implementation period, some allowances may have to be made for inflation, changes in technique and possible increases in operational efficiency.

The plan will prescribe how expenditure will be recorded. Expenditure is subject to audit and the records must account for all funds disbursed, and should give a measure of the overall expenditure of the project at any point in time. When, during implementation, actual expenditure is compared with the budget for a specified period, this should give some measure of planning and management efficiency. Expenditure for labour and staff is usually recorded on muster-rolls or pay sheets, while equipment and store charges are recorded by requisition and receipt.

Revenue is generally slight during the establishment phase of a plantation, but is generated fairly rapidly through the thinning to the final felling phase. A forecast of revenue by years is usually made. It is essential that the plan prescribe an adequate system of accounting for such revenue, recording the amount, the product, the source and the date of occurrence and payment.

Expenditure and revenue are usually recorded in debit and credit ledgers, and balances may be taken at defined intervals but always at the end of the financial or accounting year.

Costings, Records and Control

Complex costing and recording systems are costly to administer and very often run into difficulties and fail. It is essential, therefore, to keep them simple, particularly at the field level, and to record only essential data. The plan will prescribe a system of project control. Such control is concerned with 1) maintaining the work output at the levels set in the programme of work and 2) keeping the costs within the limits estimated for particular operations in a particular period.

There are many types of "periodic progress reports" which simultaneously record work completed and give a breakdown of project costs. Such progress reports, which are often compiled on a monthly basis, must be accurate and submitted punctually. The reports generally record for defined periods the items given below as the headings for a sample form:

| Operations and Cost Code | Units | Inputs and costs | | | | | | | Work Completed | Unit Cost |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Labour | Cost | Plant vehicle & machines | Cost | Materials | Cost | Total | | |
| | | | | | | | | | | |

The physical inputs are measured by defined units such as man-days for labour, hours for plant or tractors, kilometres for vehicles, and number, weight or volume for materials. Standard unit costs are periodically laid down for these items and used to calculate input costs. The physical outputs are measured by such units as metres for roads, hectares for planting or weeding and thousands of plants for nursery production. The report may also incorporate at this stage, or a later stage 1) the plan forecast of outputs and costs and 2) cumulative actual outputs and costs, and these figures form the basis of the prescribed control system. It is usual to give a code number to each operation, for ease of operation and for possible computer processing. The project report gives a breakdown of costs; under plantation operations, for example, there would be a number of subheads covering land preparation activities, phases of planting, mechanized weeding, hand-weeding, fertilizing, pruning and so on. The plantation or project manager uses such costs for economic appraisal and control. Where there are variations in actual unit costs, it should be possible to select and develop the more efficient alternatives. It is necessary to train supervisory staff in compiling such reports and to impress upon them the value of data collected. In areas where there is a shortage of adequate field management, reports may include physical data only, and costs may be applied centrally. It is equally important that management should check reports without delay, record appreciation of efficient outputs and inquire into significant deviations from budgetary provisions or into widely variable unit costs for the same operation in different areas.

The annual total of operation costs for labour and materials should be readily reconciled with expenditure for the same period. The reconciliation of plant, vehicle and machinery costs is a little more complicated but, providing the basis of unit costs for equipment is soundly designed, a reasonable reconciliation can be achieved. The flow chart of cost records in Appendix H outlines a costing process.

The fundamental plantation record is the compartment register. The compartment register should give a comprehensive and precise description and history of the compartments comprising a given plantation. The register may be a simple or a complex document, generally recording the following information:

1) A detailed map of the plantation area;
2) Details of physical features - elevation, aspect, exposure, slope, land form, geology, soils and vegetation;
3) Site characteristics including planting suitability and site quality classes and
4) History.

The plan will prescribe that all work in a compartment should be recorded in this register which will contain a form or forms to record:

1) Site preparation and planting or sowing,
2) Tending operations,
3) Crop assessment and
4) Yields.

The physical details of work done in a compartment can readily be extracted from progress reports. Some compartment registers also record costs but, unless there is a particular reason to record costs at this level, the register is best maintained as a physical historic record. If, at some future date, the cost of operations in a particular compartment or group of compartments is required, it should be possible to extract this from the cost system records.

Map Records

The management plan, in addition to the compartment register, should have some or all of the following maps:

1) Plantation locality map (at 1:50 000 to 1:100 000 scale) and management maps (at 1:20 000 to 1:50 000);

2) Plantation soil and planting suitability map;

3) Plantation vegetation map;

4) Plantation organization map - showing present roads, compartments, nurseries and planned layout;

5) Planting and site preparation map - showing present state and planned programme;

6) Plantation tending map or maps - showing present state and planned programme for major operations - and

7) Fire protection maps - showing present state and planned programme.

The management maps can be prepared on a basic map with a series of overlays for the different information. The number of maps may be reduced by combining certain data from separate but related sheets. The management maps form a visual record and control of plantation operations, and the plan will prescribe that specified management maps will be brought up to date on a periodic or annual basis.

In conclusion, it should be noted that the plantation management plan can take many forms, and it is only a tool for translating policy and objectives into reality. The real measure of efficiency is not how well it is designed but how successfully it is implemented. Good management needs not only good planning but good implementation.

## ANNUAL PROGRAMME OF WORK

This covers the next operational year and needs to be prepared a few months in advance of the start of the year, to leave time to have the budget approved and to provide the resources needed (Fraser, 1973). The planning can be done on forms divided into monthly or weekly periods giving a forecast of the quantity of work to be done during each period by operation. After a plantation management plan has been smoothly executed for several years, there should be little difficulty in compiling the annual programme of work directly from the plantation management plan.

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Appendix A

## CRITERIA FOR SUCCESSFUL LINE PLANTING

(By H.C. Dawkins, quoted by A.F. Lamb, 1969)

There are a number of criteria which must be met if a system of enrichment is to produce a satisfactory stand of timber trees. These criteria have been clearly enunciated by Dawkins and are quoted with his permission:

In the sense used here, enrichment by line-planting is the establishment of a tree crop to be closed at rotation age, in lines spaced at intervals equal to or slightly greater than estimated final-crop crown diameter.

There are five necessary conditions for line planting, in addition to the normal requirements of healthy plant establishment:

1. There must be little or no demand for thinnings in the area concerned. If thinnings are required, the method is unsuitable; if large timber and veneer logs are in demand, the system is suitable.

2. The species planted must be fast-growing (1.5 m of height per year as a minimum), naturally straight and self-pruning, i.e. generally of the colonising or gap-filling, light demanding type.

3. There must be no upper canopy; only clear-felled, clear-poisoned or low secondary forest is suitable.

4. The regrowth between the planted lines must be non-inflammable; or control of fire must be complete.

5. Browsing animals must be absent, scarce or of negligible effect on planted trees.

Provided all five conditions are met, the method can cut the cost of a final crop to less than a third of what would be incurred by close planting. The technique then requires the following:

6. Planting lines should be spaced equal to or slightly more - up to 20% more is reasonable - than the expected crown diameter of healthy final crop trees of the species concerned. The reason for this is to prevent any possibility of serious between-line crown competition before maturity, to save on establishment costs and to give more scope for possibly superior species which may arise naturally between the lines.

7. Plants should be spaced along the lines at approximately one-fifth of the spacing between them to allow a selection of about one-in-four for the final crop. If poisoned overwood is likely to be abundant, as in very lightly felled natural forest being planted, then up to 30% losses must be expected and spacing in the lines should be nearer 1/6th to 1/7th of spacing between lines. Only by this means can good form of the final crop be assured.

8. Planting lines must be well-cleared, about 1.8 m wide at first, and made easy to move along, at least along one side of the planted trees, by removal of most if not all woody snags. Once planted, the lines must be kept clean and no overhanging or threatening growth tolerated. Since this clearing work is confined to a very small fraction of the area, labour costs are low and several cleanings (sometimes up to six or seven are necessary) can be afforded in the first twelve months.

9. Plants must get away to a quick start. For most species this means using potted stock; stumps or striplings are not likely to be suitable. Cedrela has shown itself capable of starting from direct seed, but this is quite exceptional.

10. Planting must follow immediately on clearing the planting lines; clearing in the early dry season, and planting three to five months later in the early rains is a thoroughly bad technique and will result in at least two more clearings than otherwise. Poisoning of the upper canopy also should be timed to let in the light at time of planting, not before, it is recognized, however, that this is not a precise possibility.

11. Trees arising between the lines, unless superior in value to the planted species, must be cut or poisoned immediately they "threaten" the plants, i.e. before they overshadow them. The greatest threat is from Musanga, Trema and Macaranga. Similarly, climbers over-arching from the bush regrowth beside the lines, must be vigorously cut back before they overshadow the plants, provide ladders for other climbers or obstruct quick access along the lines.

12. Thinning along the lines is a matter of selecting the stems of superior form and height. (Unless the disparity in size is very great, form and height should both be regarded as more important than mere girth). The first thinning will generally be at three to four years, by which time the trees should be well above the shrub and climber regrowth. It will probably require about 50% culling of the crop.

The above five principles and seven technical guides must be taken very seriously. Line-planting has very commonly failed and has a bad reputation among English-speaking tropical foresters because one or other of the principles has been flouted. If all the above are followed for a species sensibly chosen, the technique has a very high chance of success in tropical forest conditions.

Appendix B

## GUIDELINES FOR THE DESIGN AND ESTABLISHMENT OF PLANTATION ROADS

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### PLANNING

The object and purpose of establishing a plantation road system is to provide a network of roads which is sufficient to enable planting and tending to be carried out in timely fashion and at the lowest possible overall plantation cost, while providing rapid access for protection purposes and a network of roads suitable for the eventual extraction of the final product.

There are no hard and fast rules for planning road networks in areas which are to be afforested. Any plan must take into account both the immediate and future requirements for roads. Since, initially, access will be required for the planting operation, the planner must consider the rates of planting which can be achieved with different road densities and spacings. These are not easy to determine without reliable data on the productivity of planting crews, off-road capabilities of vehicles and road construction costs, but the road plan must aim at reaching a balance between planting rate, as affected by carrying distances, and the cost of road construction.

The need for rapid access in case of fire or other emergencies must be considered in the road plan. In particular, each major plantation block should be reachable by more than one all-weather road, so that access of fire suppression crews and equipment would still be possible even if one main road was blocked or otherwise impassable.

When planning the road network the planner must also bear in mind the ultimate use of the produce from the forest. Since in most cases the forest being established is to be harvested, care must be taken to ensure that the location of major roads to be constructed for planting will be located to suit the future logging methods. It is not always possible to know in advance what logging system will be used ten or even twenty-five years hence, but the planner must avail himself of the best existing data on logging methods to assist him in making his decisions.

Although the full road network should be planned before plantation establishment begins, costs can be minimized by delaying construction until the roads are actually required. It should be remembered that road costs form a large part of total plantation costs. Roads for planting and tending are therefore only built as they are needed and only to the lengths and standards required for these operations. During the establishment phase it is not necessary that roads be built to logging road standards with high load bearing capacities since unnecessary expenditure would be carried the length of the rotation, thus raising overall cost. However, the basic network will be available for updating and extension for later harvesting operations.

In areas being converted from natural forest to plantations, the planning of the road network prior to primary logging, as well as the physical location and construction, is of utmost importance for, unless unusually stringent conditions and additional road requirements are imposed, this network will be written off against the logging and will not be a financial burden to plantation establishment.

## ROAD MAPS

Road locations should be indicated on maps of suitable scale; contour maps are best suited for this purpose. A map scale of 1:25 000 serves well for moderate sized plantations in the order of 25 000 hectares since it can be hung on the wall for easy viewing and is not too small to show necessary overall planning detail. This master map should show all existing and proposed roads, important natural physical features such as streams, mountains and such other major details as planting blocks, firebreaks, lookout towers, nurseries and buildings.

Maps showing roads in annual planting areas or plantation blocks should be available at a scale larger than for the master map and should show all relevant data in greater and finer detail. A map scale of 1:5 000 gives good detail and is compatible with the 1:25 000 scale of the master map.

For roads in which even finer details are required (e.g. for rebuilding or tendering), maps and construction plans should be at a maximum scale of 1:1 000. Where necessary, profiles of roads should be produced using a ratio of horizontal to vertical scales of 10:1 or 20:1 as dictated by the terrain.

## ROAD INDEXING SYSTEM

A road indexing or numbering system, with accompanying map, is an essential part of any forest plantation programme. Roads must be numbered so that staff and others can be easily directed to any part of the plantation. The system must be systematic and take into account the various classes of roads and the major areas they serve. Since roads do not often stop within any one annual planting area, a designation by years is difficult to devise, however, a simple numerical system is easy to formulate and is effective.

## ROAD CLASSES

A system of road classes designed to meet the needs of planting, fire suppression and efficient supervision is given below. These classes are considered adequate for the establishment of a plantation in one large contiguous area; however, as experience is gained the planner should not hesitate to adjust the system to more adequately meet the plantation requirements and/or to lower costs. The basic network when properly aligned to fit the terrain will also serve the harvesting function.

Classes

1 **Main Road**

This forms the main access from the highway or public road system to the headquarters area and to the extremities of the plantation. It provides speedy, all weather travel.

2 **Branch Roads**

This secondary system of roads is designed to move traffic from the main road to the planting areas in all weather, at moderate speeds. The branch roads form the major access system within each annual planting area.

3 **Spur Roads**

These are basic utility roads designed to move planting and tending crews to work sites at generally low speeds in four-wheel-drive vehicles. They will not be all weather, with the exception of portions of the longer spurs which will be surfaced so that the end of any spur is not further than about 1.5 km from a surfaced road, as measured along the spur.

4 **Planting Tracks**

These simple, bulldozed and levelled tracks are the most numerous of all classes of roads and serve the basic needs of planting and tending. They are suitable for four-wheel-drive machinery and have an absolute minimal number of culverts and bridges.

Road classes 1, 2 and 3 are located and staked on the ground prior to logging and land clearing. Class 4 roads are located after clearing and burning has been completed; however, location prior to clearing, if possible, is advantageous. Road classes 2, 3 and 4 are built in the proportions of 1:2:4 or as near as practical to this.

## DENSITY AND SPACING OF ROADS

The density of road network required will vary significantly from one plantation to another, but a figure of 2.5 km of road per $km^2$ of gross plantation area is a reasonable estimate of the average requirement of many plantations. At this density, and at the proportions of 1:2:4, the number of kilometres of class 2, 3 and 4 roads required would be:

| Road Class | | Km of road per $km^2$ of Gross Plantation Area |
|---|---|---|
| 2 branch | | 0.35 |
| 3 spur | | 0.71 |
| 4 planting track | | 1.44 |
| | Total | 2.50 |

Main roads may be included in the above overall distances when any sections can be used for plantation work.

At this density, average spacing between roads would be 400 m. Lacking accurate information on the capabilities of planting teams, this is a reasonable estimate of the planting track spacing on which initial planning can be formulated. Later spacing of planting tracks should be based upon the distance at which a planting team can reach the optimum daily average number of trees planted. As experience is gained and efficiency improves, therefore, the spacing and overall length of planting track required may change. The spacing will also vary to some extent due to terrain.

The location of branch and spur roads will also often be dictated by topographic constraints but will, in general, adhere to the above quoted density.

## ROAD STANDARDS

Standards should be applied in the light of topographic, soil and weather conditions as they exist, or as they affect road construction costs and rate of construction. In other words, although standards will be laid down to which the location engineer will try to adhere, he should alter these to suit conditions as he finds them, bearing in mind that the raised or lowered standards must not have a major effect on the usability of the road. In other words, he should bear in mind that the roads are being built to achieve the lowest possible overall plantation cost at maturity.

Road standards for two terrain classes and the four road classes are detailed in table A1. The following notes refer to the standards in the table and their application.

### Right of Way Width

This represents the piece of land set aside for the road. It is the overall width which is to be cleared and in which trees are not to be planted. This extra distance, over and above the actual road works, facilitates more rapid drying of the road after a rain, makes allowance for future widening and improves visibility.

### Subgrade Formation

Ample allowance should be made for the traffic density contemplated and to allow drainage away from the running area. In mountainous terrain where slopes are extreme, the road bed must be full bench (not on fill). All fills must be compacted.

### Side Cuts

Side cuts will vary with the topography, but as a general rule should be at a slope of 1:2 or less.

### Turnouts (Laybyes)

Turnouts need not always be evenly spaced, but should be positioned so as to be used to maximum advantage to allow vehicles to pass and to avoid accidents. Turnouts will also be used as parking places for vehicles which carry crews and materials.

Table A1

## ROAD STANDARDS 1/

| Item 2/ | Flat, Rolling, Undulating Terrain | | | | Mountainous Terrain | | | |
|---|---|---|---|---|---|---|---|---|
| | Main | Branch | Spur | Planting Track | Main | Branch | Spur | Planting Track |
| Right of way width | 20 | 15 | 12 | 5 | 20 | 15 | 12 | 5 |
| Subgrade width | 5 | 4 | 3.5 | 3.5 | 5 | 3.5 | 3.5 | 3.5 |
| Ditch width | 1 | 0.6 | 0.6 | Minimal | 1 | 0.6 | 0.6 | Minimal |
| Pavement (a) Width | 3.5 | 3.0 | 2.5 | - | 3.5 | 2.5 | 2.5 | - |
| Pavement (b) Thickness (cm) | 10(Min) | 10(Min) | 10 | - | 10(Min) | 10(Min) | 10 | - |
| Gradients(%)3/ (a) Maximum Adverse | 6 | 8 | 10 | 15 | 6 | 8 | 10 | 15 |
| Gradients(%)3/ (b) Maximum Favourable) | 8 | 10 | 10 | 15 | 8 | 10 | 10 | 15 |
| Curvature, minimum radius | 120 | 60 | 30 | - | 85 | 60 | 30 | - |
| Turn outs (a) Per kilometre (No) | 6 | 5 | 3 | 3 | 6 | 5 | 3 | 3 |
| Turn outs (b) Width x Length | 4x15 | 4x12 | 4x12 | 4x12 | 4x15 | 4x12 | 4x12 | 4x12 |
| Culvert type | Concrete | Wood | Wood | Wood 4/ | Concrete | Wood | Wood | Wood |
| Bridge type (Wood) | Crib and or sill, log stringers, timber deck | Crib and or sill, log stringers, earth covered | As Branch | As Branch if necessary | Crib and or sill, log stringers, timber deck | Crib and or sill, log stringers earth covered | As Branch | As Branch if necessary |

1/ Originally devised for a planting schedule of from 1 500 to 2 000 ha per year.

2/ All figures in metres unless otherwise stated.

3/ Adverse and Favourable grades not applicable during establishment phase, however due attention must be paid to these to avoid reconstruction in the harvesting phase.

4/ Hollow log permissible.

In flat country spacing can be equidistant, however, in mountainous terrain turnouts should be placed at either end of the sharpest curves or, in the case of a road curving around a sharp ridge, the turnout can be placed on the outside of the curve, at the nose of the ridge, to take advantage of the fill area and also to ensure good visibility. Borrow pits should be used as turnouts wherever possible.

For those roads which are to be surfaced the turnouts should be surfaced to the same standards.

## Pavement

Surfacing material should be of either hard, crushed rock or of best quality laterite with ample ferrous concretions or other suitable materials approved by the construction supervisor.

The pavement thicknesses as laid down in the table of standards, are compacted thicknesses and are those considered to be suitable for the traffic in the establishment phase. These are not, however, to be construed as rigid standards, but might be varied in the light of what the supervising engineer finds, as construction experience is gained in the area.

On both the main and branch roads the running surface widths should be ample for the type of vehicles expected to use the road such as trucks carrying planting stock, fertilizer and work crews, not normally heavily laden nor of extraordinary large size. Much traffic will be of the type provided by four-wheel-drive vehicles. The surface width of the road will however gradually widen through the shifting of material from the centre to the shoulder; this will be caused by the passing of vehicles which throw material and by the maintenance road grader which will spill small amounts as it makes its passes. Eventually, for roads with wide formations, passing will be possible without the use of the turnouts. Similarly, superelevation will be built up at the curves by fast moving vehicles. Adequate camber (crown) should be provided to ensure proper drainage.

Spur roads need not be surfaced along their entire length. It is normally sufficient to surface only some stretches with the criterion that the end of any spur road is no further than 1.5 km away from a surfaced road, as measured along the spur. Estimates often indicate that only some 20 percent of the total length of spur road requirements will be surfaced.

It should be noted that in some regions which are lacking in surfacing materials, the cost of surfacing is often the major portion of total road construction costs.

## Curvature and Travel Speeds

The minimum radii of curvatures have been set at a level at which minimum travel speeds, on class 1, 2 and 3 roads, can be maintained. By setting these standards as the minimum, it can be expected that most radii will be greater, thus allowing for greater speeds and thereby maintaining minimum average speeds over the longer distances.

Average travel speeds of 65, 50 and 35 km per hour, for main branch and spur roads, respectively, have been used as the criteria which will provide for reasonable travel for work crews and good travel speeds for fire suppression crews, bearing in mind the added road costs which would accrue by putting in curves with much longer radii. These speeds might be slightly lower in mountainous terrain, for which minimum radii as shown in the table of standards have been shortened.

## Gradients

Road grade standards have been set to counter the effect of erosion and to keep maintenance costs to a minimum as well as to ensure effective travel time. Long sustained grades should be avoided by the allowance of grade breaks in the profile.

## Drainage

Since it is impossible to discuss the amount of rainfall which any one plantation area might receive, it will suffice to point out a few factors which should be considered by plantation managers, in providing adequate road drainage.

Areas with a heavy annual rainfall will need a better drainage system than those in dry areas; however, it must be remembered that in some regions, though the annual rainfall can be considered as moderate (say to 2 000 mm per year), a large portion of this might arrive in a short period of time, and thus the drainage system must be geared to handle the large periodic volume.

The forces exerted by large volumes of water, collected and diverted by a road system can cause severe damage to roads and extensive erosion. These effects can be overcome through proper ditching and channelling of the water to points where it can do less damage.

In flat terrain, ditches should be constructed on both sides of the road with adequate cross drainage and lead-off, whereas in mountainous terrain the upper side should be ditched. In rolling terrain, culverts should be placed at the bottoms of fills.

In all types of terrain, roads must be constructed to cross watercourses in such a manner as not to impede the natural flow of water. This can be effected through the use of the proper size of culvert or bridge. Culverts should be laid so as to prevent ponding. Water should not be allowed to run (and gather more water) for long distances in ditches on long, continuous sloping roads; its flow should be broken by barriers and led off by adequate cross drains at appropriate places. Culverts should not be situated so as to drain onto fill unless special structures (e.g. rip-rap) are built to preserve the fill.

On roads with long continuous grades, where surface water is liable to collect and run down the running track of the road, removing surface and subgrade material in its course, open surface-drains should be constructed to remove this concentration and prevent the deterioration of the road.

In general, bridges can be of simple construction and if built of the most durable woods should last at least the life of one short rotation. Two types of bridges are common: one having timber running planks and one covered with soil and surfaced. Both types make use of log stringers which rest on either cribbing or on a mud sill.

## Cross-Sections

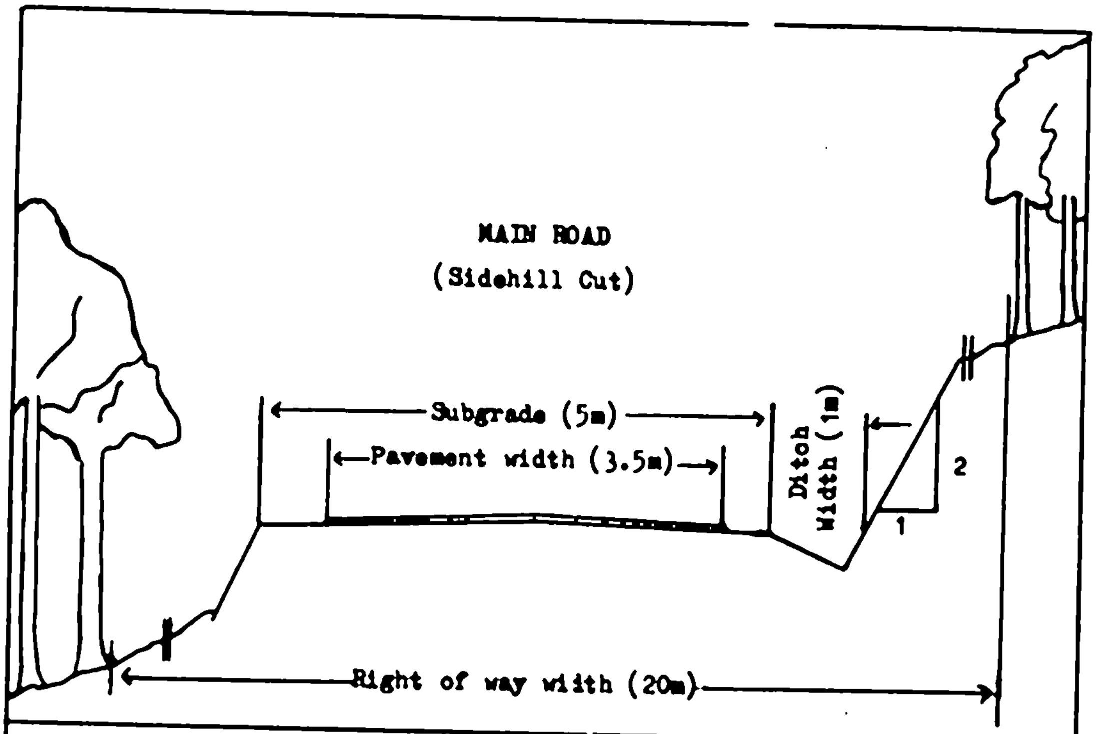
Typical cross-sections for main and branch roads are shown in Figure B1.

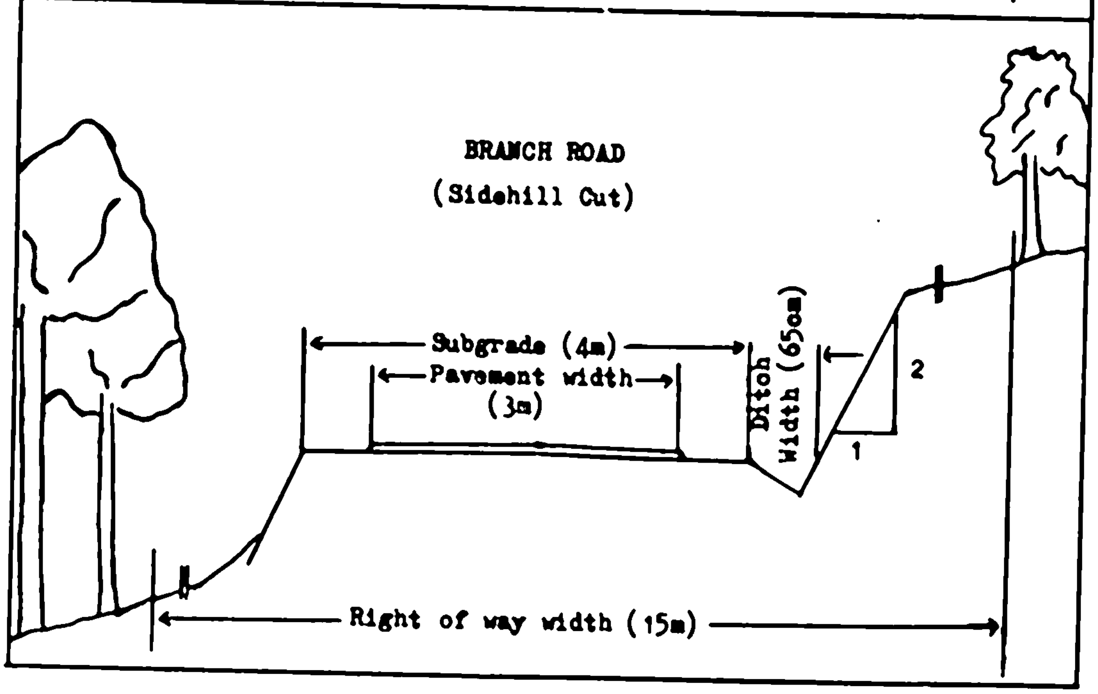
## Maintenance

Maintenance must be a continuous procedure once the road system is started. This can be effected through the use of maintenance machinery (e.g. road graders, tractors, front-end loaders, tipper trucks) which may (preferably) be owned by the project and operated by a maintenance crew. Maintenance crew labourers should also clean culverts and ditches and clear brush from around ditches and tight corners on a regular basis.

Figure B1

CROSS-SECTIONS OF TYPICAL PLANTATION ROADS



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Appendix C

## AN OUTLINE OF EQUIPMENT AND MATERIALS FOR AN AFFORESTATION PROJECT

| OPERATION | EQUIPMENT | MATERIAL |
|---|---|---|
| Land clearing | Survey equipment<br>Crawler tractors<br>Anchor chains<br>Dozer blade<br>Stinger<br>Front-end rake<br>Root plough | Herbicides<br>Fuel and oil<br>Hand tools<br>Aerial photographs |
| Ground preparation | Tractors 50-100 hp<br>Disc ploughs<br>Angledozer blade | Herbicides<br>Fuel and oil<br>Hand tools |
| Nursery | Wheel tractor<br>Trailer<br>Loader attachment<br>Loader attachment<br>Sprinkler equipment<br>Soil mixer<br>Hand tools: spades, forks, hoes<br>Spraying equipment | Fertilizers<br>Pots<br>Potting media<br>Insecticides<br>Fungicides<br>Herbicides<br>Fuel and oil<br>Hand tools |
| Planting | Tractors, 50-100 hp<br>Trailer | Fertilisers<br>Fencing stakes<br>Fencing wire<br>Hand tools: spades, mattocks<br>Fuel and oil<br>Tree carrying containers |
| Maintenance and protection | Tractor, 50-100 hp<br>Soil cultivators<br>Pruning saws<br>Fire towers<br>Fire engines<br>Water pumps and hoses | Fertilisers<br>Herbicides<br>Fuel and oil<br>Insecticides<br>Hand tools |
| Road construction | Bulldozers<br>Tipping trucks<br>Graders<br>Excavators<br>Rollers, rubber tyred | Culverts<br>Fuel and oil<br>Road ballast and gravel<br>Bridge materials<br>Cement, Gelignite |

Appendix D

## PLANNING OF SEED COLLECTION AND HANDLING 1/
(Example)

### I. Background Data

A. SEED DEMAND

| | | |
|---|---|---|
| 1. | Species | *Eucalyptus camaldulensis* |
| 2. | Plants per ha | |
| | (a) Number planted | 1 110 (3 x 3 m) |
| | (b) Add field replacements at 20% | 222 |
| | (c) Total requirement - plantable plants | 1 322 |
| | (d) Add losses and culls in nursery at 15% 2/ | 235 |
| | (e) Total requirement - germinated seeds | 1 567 |
| | Ditto rounded upwards = | 1 600 |
| 3. | Estimated number of germinated seeds per kg of uncleaned seed | 400 000 |
| 4. | Kg uncleaned seed needed per ha of plantation | 0.004 kg (c. 250 ha per kg) |
| 5. | Annual planting area | 250 ha |
| 6. | Annual requirement of seed | 1.0 kg |

1/ from "Report on the FAO/DANIDA Training Course on Forest Seed Collection and Handling", Vol. II. Rome, FAO. FOR:TF - RAS 11 (DEN), 453 p., 1975.

2/ Losses and culls represent 15% of the germinated seeds. This is equivalent to approximately 18% of the surviving plantable plants.

B. SEED SUPPLY

| | | |
|---|---|---|
| 7. | Sources for seed procurement | Local seed stands |
| 8. | Seed harvest, expected yield/ha | 5 kg per ha |
| 9. | Minimum area of seed stand required | 0.2 ha |
| 10. | Area of seed stand available | 1.5 ha |
| 11. | Seed harvest, periodicity | Annual, reliable from stands over 10 years |
| 12. | Season of collection | Early dry season, June - July |
| 13. | Special problems of collection | None |
| 14. | Rate of seed collection | Equivalent to 100 - 200 g uncleaned seed per man-day |
| 15. | Length of period for seed extraction | 10 - 15 days (sun-drying) |
| 16. | Special problems of extraction and cleaning | It is not possible to separate the chaff from the seed. Both chaff and seed are therefore sown together. |

C. SEED STORAGE

| | | |
|---|---|---|
| 17. | Normal season of sowing | Late dry season, September - October |
| 18. | Length of period between collection and sowing | |
| | (a) if sown in same year | 3 - 4 months |
| | (b) if stored for more than one year | Not applicable |
| 19. | Storage capacity needed | |
| | (a) Net seed space at S.G. 0.5 = 500 kg per $m^3$ | .002 $m^3$ (one jar of two-litre capacity) |
| 20. | Special problems of storage | None |

D. PRETREATMENT, TESTING, SOWING

| | | |
|---|---|---|
| 21. | Special problems of pretreatment | None |
| 22. | Special problems of testing | It is difficult to separate the chaff from seed. Identification of the species from seed is not possible. |
| 23. | Special problems of sowing and seedbed handling | The seed being very small has to be sown with sand. |

## II. Estimate of Needs

### A. COLLECTION

| | |
|---|---|
| 1. Methods recommended | Climbing |
| 2. Equipment/transport recommended | Safety belts and lines, boots and spurs. Temporary use of land rover. |
| 3. Staff/labour recommended | 5 - 10 man-days and one supervisor |
| 4. Remarks | Climbers should be insured. Seed stand protection and management must be ensured, since normal stands, cut on 6 year coppice rotation, bear very little viable seed. |

### B. EXTRACTION AND CLEANING

| | |
|---|---|
| 1. Methods recommended | After sun drying, capsules are to be vigorously shaken and sieved manually. |
| 2. Equipment recommended | (1) Tarpaulin<br>(2) Sieves |
| 3. Staff/labour recommended | A forest guard and two labourers |
| 4. Remarks | No cleaning need be done as the seed is sown along with the chaff. |

### C. STORAGE

| | |
|---|---|
| 1. Methods recommended | Storing in a cool well-ventilated room in tins, jars or cotton bags. |
| 2. Equipment recommended | Tins, jars, cotton bags |
| 3. Staff/labour recommended | No special staff required. The staff recommended under "Extraction & Cleaning" will do this work also. |
| 4. Remarks | Storing of seed is no problem, because the storage period is only two or three months in the dry season, when atmospheric humidity is low. Room temperature in a well-ventilated room averages 25 - 30°C during the storage period. Regular annual seed crops and the fact that the seed stand area is capable of producing, in a normal year, at least seven times the annual requirement of seed precludes the need to carry stocks from one year to the next. |

### C. PRETREATMENT

None required

Appendix E

# NETWORK ANALYSIS 1/

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An afforestation project is composed of a great number of activities which are spread over an extensive tract of land and involve a large number of people. Because of the influence of seasonal factors, many of the activities which must be carried out to complete the project are highly dependant on correct timing.

Given unlimited time and money, there would be no problem as work not done in one season could be postponed until the next, and activities dependent on the completion of other tasks could be delayed until the first tasks were finished. In practice, there are strict time and monetary limits, and the project manager is faced with a complex problem of scheduling and controlling all the activities so that the whole programme of work needed to complete the project is carried out within the time and money limits that have been set.

This problem is common to managers of all business enterprises, so that in recent years a number of techniques have been developed and their use expanded for dealing with such scheduling problems. One of the best techniques for controlling and scheduling complex operations is network analysis, which is concerned with optimising the performance of a complete system such as an annual planting programme or all the operations involved in the afforestation of a particular tract of land. It is not concerned with the task of optimizing the physical effort involved in carrying out each of the activities which go to make up the complete system. The latter is the concern of work study, which looks at the individual routines, e.g. the best tools or methods of planting a tree.

1/ from "A manual on the planning of man-made forests" FAO, Rome. Working Paper FO:MISC/73/22, 129 p., 1973

The opportunity for saving time and money on large-scale projects by optimising the logical sequence of events is frequently very great. When operations become more or less routine, there is a tendency to think that few opportunities exist for further improvement, but it is surprising how often it is possible to make up time after an unexpected delay. This indicates that many operations could be speeded up, or by changing the sequence in which they are performed, that it is possible to improve on the overall performance of the system.

With complex tasks such as a large afforestation project it is too much to expect that they can be completed on time without a constant watch on the progress of each of the component activities. This watching of progress is virtually impossible without some technique which enables the manager to condense the whole project to some simple form, and represent the component parts graphically, so that all the interrelationships can be seen at a glance.

Network analysis (sometimes referred to as programme evaluation and review technique, PERT) is a graphical form of representing all the component parts and the interrelationships of a complex operation - something like the orchestra conductor's score.

The basis of network analysis is the representation of the component activities and important events such as the start and finish of each activity in a graphic form in the logical sequence in which they must take place. The convention used in most networks is to represent the events as circles, connected by arrows representing the activity thus:

Figure 1


The logical representation of a whole operation calls for the time to flow in one direction, so that the earliest activities are represented on the left, and later activities are put to their right. As each of the activities are incorporated, a network is built up which shows from left to right the sequence in which they need to be performed. To fix the position of any activity within the network it is only necessary to determine which activities must precede it and which can run concurrently. Some operations can run concurrently with others but cannot finish before them, so that it is particularly important to determine which activities control the start and finish.

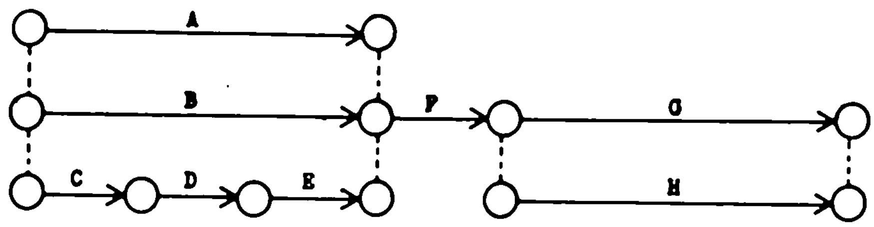
As a simple example of the construction and use of a network, consider the activities involved in planting an area of cleared land. The main activities involved are:

| | Activity | Relative Time |
|---|---|---|
| A | Mark out planting spots | 8 |
| B | Dig planting holes | 16 |
| C | Lift plants in nursery | 4 |
| D | Transport plants to site | 1 |
| E | Carry batch of plants from transport to holes | 1 |

| Activity | Relative Time |
|---|---|
| F Place plants in hole | 1 |
| G Fill holes | 4 |
| H Apply fertilisers | 4 |

Activities A, B and C can all commence together, but A must finish before B. D cannot start until C is complete, and E cannot start until D is complete. F cannot start until B and E are complete, while G and H cannot start until F is complete. G and H must start together, but H cannot finish before G. The relationship between these activities therefore can be represented as follows:

Figure 2




Such a line graph of the activities enables checks of the logical sequence of the activities to be made, and errors such as situations where the sequence in a closed loop is reversed, or where activities are left dangling, in an open loop, can be eliminated. Two basic rules which must be followed are:

1) All events except the first and last must have at least one activity entering and one activity leaving it.

2) All activities must start and finish with an event.

Having worked out the logical sequence as above, the next stage is to insert a time scale in order to assess the overall performance of the network and the operation. Assessing the time required for each activity is not always easy. The most reliable estimates are derived either from past records or from work studies, but in the absence of these it is necessary to estimate the time. If possible, estimates should be made of:

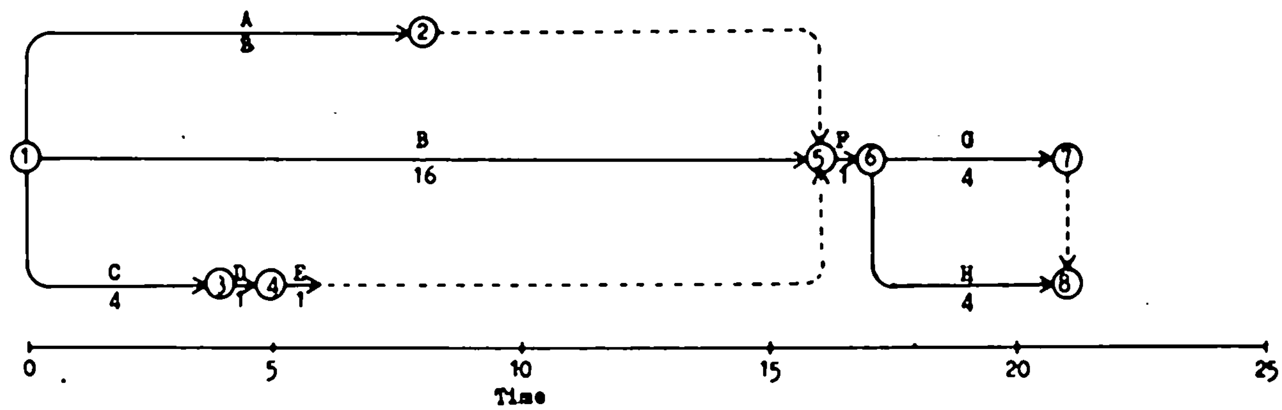
o - the most optimistic time,
l - the most likely time,
p - the most pessimistic time

and these should be weighted so that the average time is calculated by:

$$\frac{o + 4(l) + p}{6}$$

As far as possible, these estimates should be based on calculations of the time required, taking into account the amount of physical work involved and the probability of outside factors influencing the work, e.g. weather, sickness and economic factors. When the probability of an outside factor is not known, it is only necessary to estimate the most likely time. The network can thus be redrawn with a time scale and the duration of each activity recorded as in the following diagram:

Figure 3




It is then possible to analyse the network in order to determine:

1) The earliest time that an activity can start (TE) without delaying the end of the project;

2) The latest time that an activity can start (TL) without delaying the end of the project;

3) The critical path, which is the sequence of activities which determine the minimum time in which the whole operation can be completed and is the longest path through the network;

4) The amount of float in each operation, which is the amount of time in the parts of the network which do not lie on the critical path by which the start and finish of the activities can vary without affecting the overall time of the operation.

| Activity | TE | TL | Float |
|---|---|---|---|
| A | 0 | 8 | 8 |
| B | 0 | 0 | 0 |
| C | 0 | 10 | 10 |
| D | 4 | 14 | 10 |
| E | 5 | 15 | 10 |
| F | 16 | 16 | 0 |
| G | 17 | 17 | 0 |
| H | 17 | 17 | 0 |

The table shows that in this simple example the critical path lies along activities B,F,G and H because they have zero float. The last two take 4 days and start on day 17 so that the minimum time for completing the whole operation is 21 days. There is considerable float available in the lifting of plants (C) and transporting (D and E) them. If it is desirable to minimise the time between lifting and planting, then the lifting need not be started until the latest time TL.

The less float an activity has the more critical it becomes. Following any path through the network the criticality of the path is inversely related to the amount of float, and the critical path is the one which needs the most attention by the manager in order to ensure that the whole operation is not delayed.

One other important use of a network is for setting target dates. Supposing the planting must be started or completed by a certain date, in order to avoid seasonal influences, then all the activities before the critical activity can be located in time. Thus if in the example, planting, activity F, must not start before, say, 1st April and be finished by 16th May, with the relative times given in days, then: since event 5 represents the start of planting and event 6 represents the end of planting, these dates can be substituted for the earliest time TE and the latest time TL, respectively, of the events in Figure 3, and the others calculated accordingly.

| Event No. | Earliest Date | Latest Date |
|---|---|---|
| 1 | 16th March | 29th April |
| 2 | 24th March | 15th May |
| 3 | 20th March | 13th May |
| 4 | 21st March | 14th May |
| 5 | 1st April | 15th May |
| 6 | 2nd April | 16th May |
| 7 | 6th April | 20th May |
| 8 | 6th April | 20th May |

Thus, the earliest date on which operations can start in order to be just ready to plant on 1st April is 16th March, and the latest day for commencing operations in order to have planting completed by 16th May is 29th April.

A final use of network analysis is in identifying those activities which can prevent the whole operation from being completed within a target period. If the whole operation used in the example above had to be completed within 18 days, then some activities would finish up with negative float and the target would be impossible to achieve. Under these circumstances it would be necessary to transfer resources (men) from those operations with float to those with negative float. It is easy to see from the simple example that the digging of planting holes has three days of negative slack when the total operation time must be only 18 days. The float on the lifting of plants is reduced from 10 days to 7 days, but there is still sufficient float there to suggest that the lifting could take twice as long with half the number of men, thus releasing some for digging holes. It is not always as straightforward as this because it could be that only one man would be employed on lifting plants, but the general principle of searching the activities with float for surplus resources can make a useful contribution towards the optimisation of the whole operation. If resources are reallocated in this way it is necessary to rework the network in order to ensure that the logicality is maintained, and to check for changes in the critical path.

Once a network has been drawn and operations commence, it should not be put away in a cupboard and forgotten; by continually updating it and referring to it as the work proceeds, it is possible to identify in advance where new critical paths are emerging, and therefore take steps in good time to reallocate resources in order to keep on target.

Appendix F

## MEDIUM-TERM FORECAST OF WORK 1/

| Operation | Unit of Measurement | Year 1 | Year 2 | Year 3 | Year 4 | Year 5 |
|---|---|---|---|---|---|---|
| Land survey | ha | | | | | |
| Nursery | ha | | | | | |
| Plants | (1000) | | | | | |
| Veg. clearance | ha | | | | | |
| Ploughing | ha | | | | | |
| Planting | ha | | | | | |
| Fencing | km | | | | | |
| Weeding | ha | | | | | |
| Fertilising | ha | | | | | |
| Brashing/pruning | (1000) | | | | | |
| Thinning | ha | | | | | |
| Felling | ha | | | | | |
| Road constr. | km | | | | | |
| Road maint. | km | | | | | |
| Miscellaneous | | | | | | |

1/ adapted from Fraser, A.I., "A manual on the planning of man-made forests", Rome, FAO. Working Paper FO:MISC/73/22, 129 p., 1973.

**Appendix G**

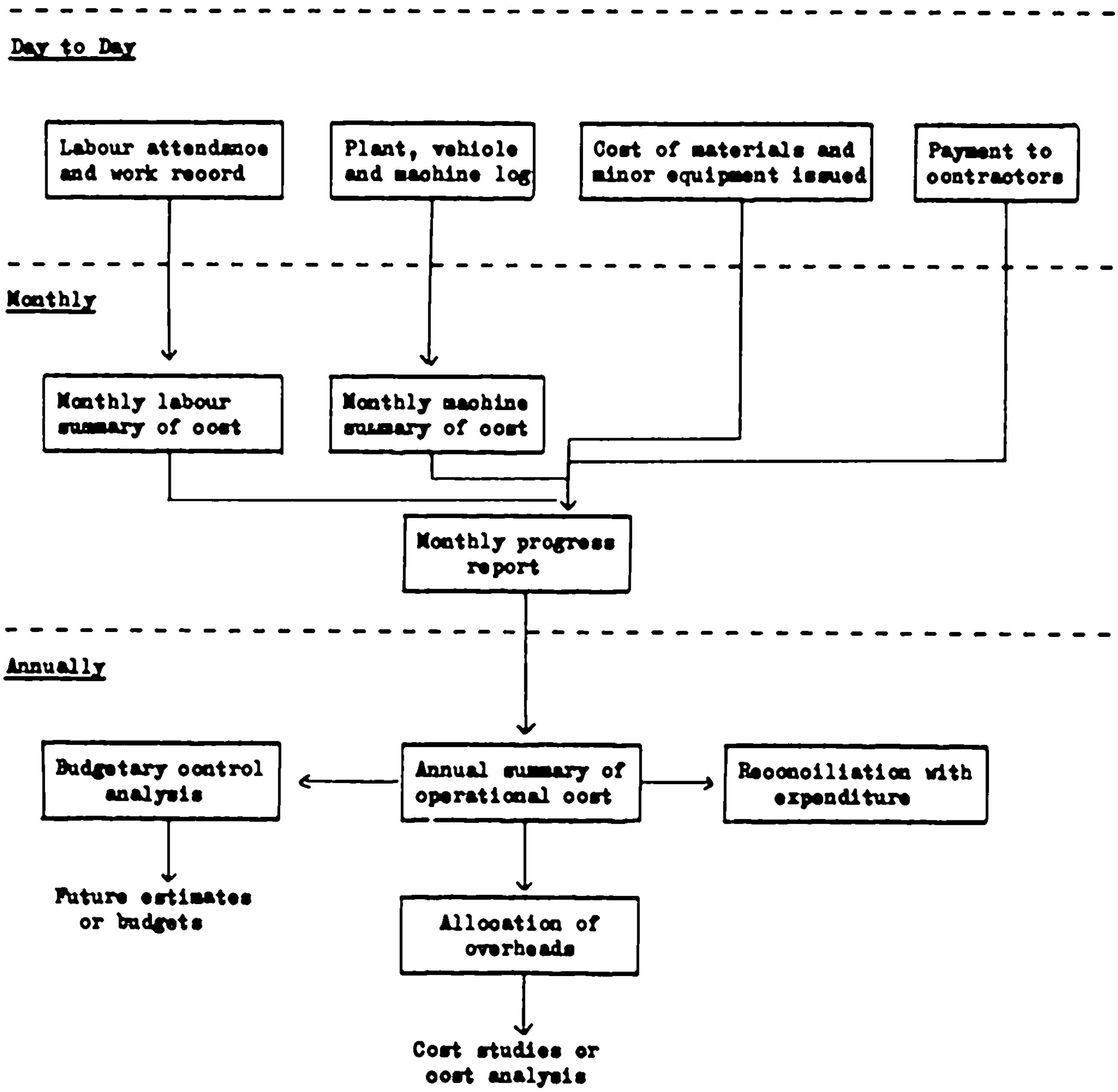
## SAMPLE DISTRIBUTION OF MONTHLY LABOUR REQUIREMENTS 1/

| Operation | Output man-days/ha | Area ha | Total man-days required per annum | Adjusted time chart for operations and distribution of labour by man-days | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | J | F | M | A | M | J | J | A | S | O | N | D |
| Planting | 6.4 | 350 | 2 240 | 560 | 560 | | | | | | | | | 560 | 560 |
| Beating up | 2.0 | 350 | 700 | 175 | 175 | | | | | | | | | 175 | 175 |
| Line cultivation | | | | | | | | | | | | | | | |
| first year | 10.00 | 350 | 3 500 | | | 613 | 612 | 613 | | | 612 | 613 | 612 | | |
| second year | 10.0 | 350 | 7 000 | | | 875 | 875 | 875 | 875 | 875 | 875 | 875 | 875 | | |
| First pruning | 4.5 | 350 | 1 400 | | | | | | 700 | 700 | | | | | |
| Total man-days | | | 14 840 | 735 | 735 | 1 488 | 1 487 | 1 488 | 1 575 | 1 575 | 1 487 | 1 488 | 1 487 | 735 | 735 |
| Distribution of total labour force | | | 52 | 31 | 31 | 62 | 62 | 62 | 66 | 66 | 62 | 62 | 62 | 31 | 31 |

1/ from Kingston, B., "Final report : plantation management" Industrial Forestry Plantations, Turkey. Rome, FAO. Working Document No.29, FO:DP/TUR/71/521, 127 p., 1977.

Appendix H

## FLOW CHART OF COST RECORDS



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